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FOREWORD.

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THIS Journal has been established for the purpose of publishing scientific contributions by officers of the Queensland Department of Agriculture and Stock. Previously these were published for the most part in The Queensland Agricultural Journal and the Technical Communications of the Bureau of Sugar Experiment Stations. The former is now essentially a farmers' journal, while publication of the Technical Communication Series has been suspended.

The Journal will be supplied free to scientific agricultural and veterinary science institutions and organizations. Exchanges are requested and should be sent to the Librarian, Department of Agriculture and Stock, Brisbane, Queensland.

THE
QUEENSLAND JOURNAL
OF
AGRICULTURAL SCIENCE

STUDIES ON NUTRITION AS QUALIFIED BY DEVELOPMENT IN *MUSA CAVENDISHII* LAMBERT.

By W. A. T. SUMMERVILLE, M.Sc., Senior Research Officer, Division of Plant Industry (Research).

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SUMMARY.

A survey of literature, and of manuscript reports and field practice in Queensland, disclosed an unsatisfactory position with respect to the manuring of Cavendish bananas and it was concluded that before sound field experiments on problems connected with banana culture could be conducted it would be necessary to obtain some more precise information on the physiology of the plant than was available. This report is an account of the work undertaken.

In the first place a study was made of the manner in which growth is manifested, and it was shown that leaf production reflected growth quantitatively and within limits could be used to measure nutritional effects. In particular it was found that the number of leaves produced in a given period is governed largely by climatic factors, but that the area of leaf produced is an index of nutritional effects.

It was found that differences in size of plants could be attributed to differences in nutrition in the very early stages of growth, but that after the production of a comparatively small area of leaf all plants increased at virtually the same relative rate over the remainder of their growing periods. The formative period is identified as that during which the meristematic tissue is laid down. The size of that organization in each case determines the absolute response of each plant, but the relative response over any particular period will be the same for all plants.

It is shown that, by the use of the area of leaf exposed, and taking into account the influence of temperature and of the duration of light, the time of initiation of floral parts can be determined with sufficient accuracy to permit of this point in the physiological age of the plant being used in the study of its development.

The development of the plant was then traced through three stages The first is occupied by purely vegetative increase; during the second both floral

and vegetative parts are produced; whilst the third is devoted largely, or entirely, to the maturation of the fruit. Further, the first stage is divided into two sub-stages, the first of which is the formative period mentioned above. It is then shown that valid comparisons between plants can be made only when cognizance is taken of the stage of development of the plant. The data show further that, for studying many questions associated with nutrition, the plants will yield as much information within approximately three months from planting as during the complete life of the plant.

The development of the flower and fruit was studied and it is shown that certain climatic factors play an important part in determining both rate of development and number of fruit. The age of the plant is also shown to have considerable bearing on the number of fruit borne, but no conclusive evidence is offered as to the effect of nutritional factors on the size attained by the fruit.

Climatic factors were found to have so great an effect on growth and development of the plant and of its fruit that it is concluded that unless the influence of those factors is assessed it is not possible to study accurately the effects of other factors such as fertilizers, and the measuring of results of treatments by direct comparisons of yields from different plants can give quite misleading results. Thus the addition of an element which the plant requires and which is deficient in the soil may lead to a reduction in yield, for it may cause the plant to develop its fruit in an adverse season of the year. The importance of time of planting follows as a corollary of this.

So far as the response of plants to the treatments used in the experimental work is concerned it is shown that added potash is associated with accelerated development, but no quantitative effects due to nitrogenous or phosphatic fertilizers were obtained. However, there are factors which preclude definite conclusions being drawn with respect to these materials.

SECTION 1.

INTRODUCTION.

Inquiries prosecuted in 1938 showed that growers of Cavendish bananas (*Musa cavendishii* Lamb.) in Queensland generally could claim little apparent benefit from the use of the fertilizers they employed, and certainly there was no evidence that as the result of previous experience any particular material or mixture of materials had commanded favour in even comparatively small communities. Though some mixtures were used more generally than others, the impression gained was that most growers worked with hope, rather than certainty, that the fertilizer would prove of benefit. Replanting of old land with bananas is rarely undertaken and consequently the industry moves more and more on to less fertile country. As this second-class land increases in proportion production figures diminish; or, at best, are maintained only by considerably increased labour and other costs. The problem of maintaining soil fertility by artificial means is thus an increasingly important one to the banana industry.

A study of the literature on the development of the banana plant and of records of experimental work with fertilizers for bananas disclosed an unsatisfactory position. The literature was almost devoid of even general information on the basic facts of the growth of the plant from the point of view of nutrition. Fawcett (1913) had written:—"The actual length of the time which is necessary from the first planting of the bulb until the period arrives when the plant commences flower formation will vary according as the conditions for growth have been favourable or otherwise. But probably the time may be safely put down as somewhere between seven and nine months." The same author (*loc. cit.*) also said:—"It is difficult to determine the length of time that elapses between the first definite formation of flowers at the base of the trunk and its appearance on emerging . . . . from the top. Doubtless the time varies considerably under different conditions, and may possibly be as short as one month or as long as two months." In 1938 the same vagueness was associated with much that needed to be understood if nutrition of the plant were to be placed on a sound foundation of knowledge.

For this reason it is scarcely surprising that failure to obtain convincing results was the rule, rather than the exception, in experiments on such questions as manurial treatments for bananas. In all the available accounts of this type of work, either in publications or as manuscript reports, yield data from experiments of comparatively short duration were the sole basis on which results were assessed. Whilst it is true that increase in total yield is the ultimate object of applying artificial manures, it must be borne in mind that the total yield over a period of years is not necessarily closely or even positively correlated with immediate production. Experience with other plants shows that quite commonly the amount of fruit is by no means the first of the products of the plant to be affected by nutrition. Nevertheless, nutrition and fruit production are intimately connected and, if the nutrition is faulty, it is certain that ultimately the yield of fruit will be adversely affected. It appeared, then, that if data on several aspects of nutrition could be gathered, and particularly if these could be correlated with yield figures, it was likely that sound conclusions as to the effect of particular nutrient materials would be possible. Accordingly a series of experiments was commenced in 1938.

STRUCTURE AND HABIT OF GROWTH OF THE PLANT.

In order to appreciate the reasons underlying the choice of methods it is necessary that some of the more important features of the structure and habit of growth of the banana plant be borne in mind, and therefore before detailing the work a short description of these points will be given.

Accounts of the general botany of the banana have been given by several authors and of these that by Fawcett (*loc. cit.*) is probably the most complete. The present paper deals wholly with the Cavendish variety, whereas most published accounts, including that by Fawcett, concern the Gros Michel. The differences between the commercial types, however, are apparently in details rather than in any general characters such as are of importance here.

The stem of the banana is normally a rhizome, surmounted above ground by the leaves, the petioles of which are successively longer and arranged concentrically so as to form a cylindrical pseudostem, at the top of which the leaf blades form a crown (Plate 1). The leaves are entire. The immature leaf is forced up through the centre of the pseudostem and is thus protected and hidden from view until it emerges at the top, or "throat" as it is usually termed. At the time of emergence from the throat the lamina is tightly wrapped around the mid-rib and the unfurling does not normally take place to any extent till the petiole has attained a slightly greater length than that of its immediate predecessor, so that the basal edge is free to unwrap.

The true stem remains underground for the greater part of its life. The flower buds are initiated at the top of this rhizome, or corm as it is most commonly called in Queensland. The first flowers are thus differentiated at just below soil level and from this time onwards the corm elongates vertically to form an aerial stalk which carries the flowers up through the pseudostem in much the same manner as the petiole has carried its lamina to the open. This flower stalk attains a diameter of about 2 inches in typical plants but in very vigorous individuals it may become more robust. As it elongates it carries up with it the last few leaves, whilst at its tip are the developing flowers. The inflorescence emerges from the throat shortly after the last leaf, and apart from the further elongation of the stalk and increase in the size of the fruit there is no further growth in the aerial portion of the plant once the flowers appear. As the stalk elongates the weight of the fruit causes it to bend downwards; so that, though it emerges directly upwards from the throat, the bunch finally hangs vertically with the distal end downwards. A varying proportion of the leaves persists until the fruit matures. The plant is then destroyed in commercial plantations, and even under natural conditions death of the aerial parts quickly follows maturation of the fruit. The original portion of the rhizome persists for some time, often several months passing before it finally rots away or is consumed by insects and other soil-inhabiting organisms.

The flowers are grouped in clusters known as hands. The hands are arranged spirally around the stalk and the number of flowers in a hand varies from about 25 to about 10, the oldest hands, that is those towards the base of the stalk, generally having the greatest number. Each hand is subtended by a bract and development proceeds in acropetal succession, each bract in turn lifting to expose the flowers which it has protected during their development. Apart from the bracts associated with the individual hands, there are larger ones which enclose the whole inflorescence during development. The number of these larger bracts may vary but normally there are two, neither of which persists long after the inflorescence appears.

Examination of the flowers in the early stages of development reveals that each is a potential hermaphrodite. Differentiation, however, takes place during development, so that commonly the opened flowers are described as being of three sorts—female, hermaphrodite, and male. This description is not accurate in the usually accepted conception of the terms as applied to flowers. In the course of development femaleness becomes dominant in those

Plate 1.

SHOWING GENERAL HABIT OF GROWTH OF THE CAVENDISH BANANA PLANT.

flowers which are differentiated first, lessening more or less gradually until maleness is so emphasized in the latest that femaleness is completely overshadowed. If the fully developed flowers are examined it is found that the proximal ones have well developed ovaries, style, stigma, and stamens. The stamens, however, do not carry anthers; nor do the ovules normally persist to fruit maturity. This type of flower, which of course gives rise to the fruit, may account for 12 or more of the basal hands. Following these femaleness is less in evidence, the ovary remains small, and the stamens become more and more pronounced; until in the distal hands anthers appear and pollen is produced, and though the style may persist it is destitute of stigma. It is to be noted that this order is invariable. This is an important point, as will be seen when the question of flower and fruit production is considered in a later section. No fertilization takes place, development of the ovary being parthenocarpic.

Propagation.

The Cavendish banana does not produce viable seed and propagation is wholly by asexual means. From the corm there arise a number of lateral buds and these provide the planting material. Two kinds of this material are commonly recognized, though botanically they are essentially the same. Either an "eye" is allowed to shoot and produce a new offset plant, or sucker, which remains in contact with the old corm for a considerable period; or the mature corm is cut into "bits," each of which carries an eye, and these bits are planted. Formerly the old corm, or butt as it is styled, was employed for planting purposes; but the banana weevil borer (*Cosmopolites sordidus* Boisd.) now makes the use of this material virtually impossible or at least inadvisable.

When a plantation has been established the new plants in turn produce suckers and one or more of these is allowed to grow from each plant so as to provide the follower or ratoon plant. The plantations are carried on in this way for as long as the plants yield commercial crops. The number of successive ratoons varies greatly and may be as low as a scarcely justifiable two or as high as 15 in outstanding cases.

PRELIMINARY OBSERVATIONAL STUDIES.

Before a method of approach to the problem could be devised, it was necessary to ascertain some more specific information on the growth of the plant than was contained in the botanical accounts of the species, and a series of preliminary observations was therefore undertaken.

Leaf Development.

The first point studied was the development of the leaf and for this purpose plants on six different plantations scattered throughout the Maroochy district in South-Eastern Queensland were selected to cover as wide a range of soil types and land aspects as practicable. The leaves were measured at weekly intervals for periods of up to six months. The measurements taken

were the length of the mid-rib and the greatest width across the blade. These dimensions were used in all subsequent work and the area of the leaf was taken as the product of the two. This is not strictly correct, for the leaf is not exactly rectangular in outline; and the smaller the leaf the greater the error was found to be.

Consideration was given to the error thus introduced and over a large series of leaves it was found to be of the order of 15 per cent. Examples are given in Table 1. That the error is not larger is due chiefly to two factors.

Table 1.

Error in Leaf Areas.

Field Measurements.	Area.	
	Calculated.	Actual.
Inches.	Sq. inches.	Sq. inches.
51 x 31	1581	1574
47 x 23	1081	979
44 x 23	1012	852
45 x 18	810	661
33 x 21	693	540
22 x 7½ ..	165	125
9 x 5	45	32

In the first place, it was found that with the technique employed in the field the tendency was to obtain smaller measurements than the true ones, particularly with large leaves. Secondly, the banana leaf rarely presents a truly flat surface but undulates, so that when laid on an even surface it does not lie flat on that surface and when pressed down there is a tendency to fold. A closer approximation to the actual area may be obtained by treating the shape as elliptical, but as in this work the figures are taken as comparative indices and not as correct in an absolute sense the introduction of this complication would serve no useful purpose. In the course of the work use is made of the function $\frac{1}{A} \cdot \frac{dA}{dt}$ but as this is invariant for any magnification transformation of A the introduction of a constant such as π will not affect the result. It may be pointed out that so far as total error is concerned this tends towards the same figure for all plants since the series of leaves produced by each plant are comparable.

In the exploratory work it was found that no change could be detected in the length of the mid-rib or width of the lamina once the leaf had been fully unfurled, so in the later stages of the work each leaf was measured only once.

As has been indicated above, the leaf is initiated at the apex of the corm and emerges from the throat with the blade tightly wrapped around the mid-rib so as to form an almost solid cylinder. The mechanism of the unfurling process has been fully described by Skutch (1930). In the preliminary work under consideration, one of the chief concerns was to discover how often it would be necessary to examine the plants in order to determine with accuracy when a leaf became fully unfurled. For this purpose, four fairly well defined stages in

Plate 2. Stage 1.

Plate 3. Stage 2.

Plate 4. Stage 3.

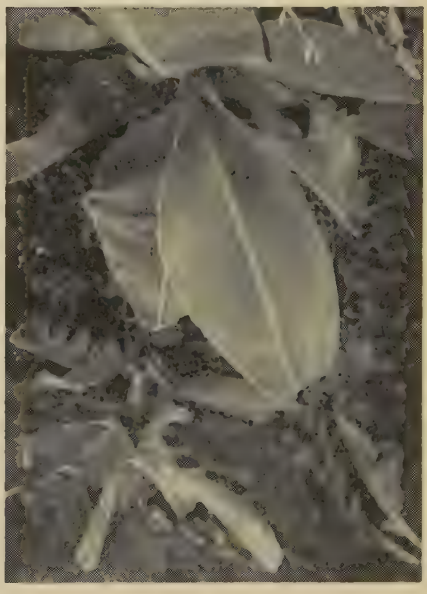


Plate 5. Stage 4.

Showing Stages in Unfurling of Leaf.

the unfurling process were taken as reference points. This work was repeated from time to time, throughout the course of the experiment, on plants which could be observed several times daily and the data from which could be conveniently correlated with that from experimental areas situated elsewhere. The

four stages will be readily understood after perusal of Plates 2-5 and may be described as follows:—

Stage 1.—The leaf is just commencing to unfurl. The mid-rib is completely extruded and the whole is of cylindrical form. The withered tip may still be attached.

Stage 2.—The unfurling has progressed so that the leaf, whilst not showing a great deal of surface, is less tightly wrapped and has assumed a somewhat conical form.

Stage 3.—The leaf shows one-half to three-quarters of the distal portion of the lamina opened, and the whole is distinctly conical in form with the apex towards the crown of the plant.

Stage 4.—The leaf is almost fully opened. The apical cross section is nearly linear, but with a concavity upwards, formed by the base of the lamina being still folded so that one side overlaps the other.

These do not, of course, represent rigid stages, since the whole unfurling process is a gradual and continuous one. The end points are sufficiently well defined, however, for a competent observer to use them as suitable references which can be regularly reproduced.

As will be shown later there are seldom great differences between plants with respect to rate of production of successive leaves under any particular set of climatic conditions. Where differences occurred they were largely accounted for by the intervals between the completion of unfurling by one leaf and the attainment of Stage 1 by the next and not by variation in the times for the actual opening.

In general, one leaf is fully unfurled before the next reaches Stage 1; but at certain times of the year, notably in the dry spring (August to October), one leaf may reach Stage 1 by the time its predecessor is at Stage 4. There is a good deal of variation in periods required for unfurling in different seasons. In March (late summer), for example, the times required were—Stage 1 to full open four days, Stage 2 to full open three days, Stage 3 to full open two days, and Stage 4 to full open one day. In July (midwinter), from Stage 3 to full open required 12 days and Stage 4 to full open five days. Any slight variation between plants could usually be readily detected. An observant worker constantly handling the figures and plants usually had no difficulty in assessing periods, and it was considered that examinations at seven-day intervals would preclude appreciable errors. The method of using the data thus obtained may be illustrated by an extract from the field notebook.

Ratoon Plant.	November 28.			December 5.		
	Leaves Produced.	Leaves Remaining.	Details.	Leaves Produced.	Leaves Remaining.	Details.
12A	36	10	S. 4	37	11	46 x 26 S. 3

At this period of the year (early summer), from Stage 3 to full open requires three days and Stage 4 to full open one day, so these entries would be interpreted as showing that the 37th leaf, which measured 46 inches by 26 inches, was produced on November 29, and another new leaf, the 38th, would be produced on December 8, though it would not be measured until December 12.

Height and Circumference of Pseudostem.

As the whole of the exposed portion of the plant is made up of leaf parts until flowering takes place, it would be expected that any other measurements would be very closely correlated with those of the leaf laminae and number of leaves.

The height of the plant is obviously dependent on the number of leaves, since the petiole nearly always elongates just sufficiently to permit full opening of the blade. There is a certain amount of variation in the excess length attained: in general, the more vigorous the plant the greater the elongation. The differences, however, are usually associated with the conditions at a particular time rather than with individual plants. Similarly the circumference at the base of the pseudostem is largely a function of the number of leaves. The circumference of the corm might be more useful but it cannot be determined without interfering with the normal growing conditions. Although it was expected that neither height nor girth of pseudostem would yield information of material value not otherwise obtainable, these measurements also were taken throughout the preliminary observational period. It was found that, over a large series of plants, excluding the juvenile period the circumference at the base in inches was slightly smaller than the number of leaves, whilst the height was approximately twice the circumference. Table 2 gives the records of 12 representative plants.

Table 2.

Relation Between Plant Measurements.

Number of Leaves.	Height to Throat.	Girth at Base.
	Inches.	Inches.
16	22	12½
19	28	15½
22	40	21
23	41	21½
28	46	23
25	47	24
30	49	25
33	54	28
30	54	28
31	56	27
36	60	30
32	62	30

Number of Roots.

The number of roots carried by a plant was found not to be closely correlated with the weight of the corm nor with other plant data. Relevant figures

are shown in Table 3. From these it would appear that a well established, vigorous plant may be expected to have between 200 and 300 roots.

Table 3.

RELATION OF NUMBER OF ROOTS TO CORM WEIGHT.

Corm Weight.	Number of Roots.
Oz.	
73	201
90	253
126	316
136	284
148	297
184	239
254	255
236	245

Banana plants when removed from the soil are commonly found to have some dead and dying roots associated with them and this has been noticed particularly in the late winter and early spring. The roots arise endogenously and it appears that, as the growth of the corm proceeds, the root may be subject to pressure which eventually causes death. An examination of any well grown corm discloses numerous channels marking the former positions of roots which have apparently died off in this way. There is no evidence that death has been due to pathogenic agencies nor that the plant has been adversely affected by this occurrence.

It may be noted that neither the weights nor the lengths of roots were taken into account owing to the difficulty of recovering all the roots from the soil.

Table 4.

RELATION OF AREA OF LEAF TO CORM WEIGHT.

Plant No.	Corm Weight.	Total Leaf Area.	Area. / Corm Weight.
	Oz.	Sq. inches.	
E2	1·3	230	177
C3	2	560	280
D4	6	1,704	284
C6	13	2,860	220
A3	22	3,530	160
F2	61	8,000	131
B5	73	10,500	144
C5	80	10,000	125
E1	90	10,400	116
A4	96	15,900	166
A5	126	15,400	122
A1	148	16,300	110
D3	184	15,500	84
B4	254	16,500	61

Area of Leaf Produced and Total Growth.

As there was a complete lack of precise information as to when floral differentiation takes place it was necessary to start observations on very young plants, and thus much of the data obtained early was of little or no use in the final analysis. The number of plants which can be quoted in certain sections is consequently small. A summary of the information of positive value in examining the relation of the total area produced to the size as measured by weight of corm produced is given in Table 4. It will be seen that, though the figures indicate certain tendencies, the general correlations are not good and the amount of growth cannot be computed solely from a knowledge of the area of leaf which the plant has produced. Other aspects of the position must be given consideration concurrently.

Longevity of Leaves.

So far the leaves have been considered only as a product of growth, but of equal importance is that growth follows partly as the result of activities within the leaf. It is necessary, then, to think in terms of the photosynthetic activity of the leaves. Since the chlorophyll appears to be distributed equally throughout the surface of the leaves, it may be assumed that the photosynthetic activity at any one time is proportional to the area, and the total amount of photosynthate which the leaf can manufacture must be governed to a certain degree by the length of life of the leaf. It is therefore necessary to consider these factors conjointly, and for this purpose the concept of day-square inches was introduced to describe the product of the area of the leaf multiplied by the number of days it remained on the plant. It must be pointed out that the efficiency of the leaf is not necessarily constant throughout life; but, as will be shown later, though an absolute error may thus be introduced, where the figures are used for comparing plants, any such error is of no consequence.

The leaf of the banana does not, like those of many plants, wither rather quickly and fall. The transition from a fully functional leaf to one quite useless in photosynthesis is, judged by appearance, very gradual; the general tendency being for necrosis to develop from the margins and the distal end. Thus weeks may be passed with an ever decreasing useful proportion. If the concept of day-square inches, or any measure dependent on it, is to be applied with tolerable accuracy it is, of course, necessary to know just when the leaf, or any appreciable portion of it, ceases to be of value in the process it is hoped to measure. In all the investigational work now being described the leaf was removed as soon as it became apparent that the chlorophyll surface was being appreciably reduced or that translocation had been adversely affected. In some circumstances a fraction only of the leaf might be affected; as, for example, where a fungal disease such as Cercospora leaf spot was involved or the mid-rib damaged by wind. In such instances, the affected portion was removed, and the necessary adjustment made to the area. In all but a few cases it was the practice to remove half the leaf instead of only a small fraction, the rule being to be drastic with removals rather than credit the leaf with capabilities about which there might be uncertainty.

The value of a measure involving the longevity of the leaves may obviously be greatly diminished if the photosynthetic potential varies appreciably with the age of the leaf, unless at the same time the various plants retain their leaves for similar periods. Consideration of this aspect of the problem is, therefore, necessary. In Table 5 are the figures obtained from plants used in the field trial which is described in the next section. Two plants in each plot are grouped and the average given in order to conserve space.

Table 5.

LONGEVITY OF LEAVES IN DAYS.

Block.	Treatment.	Month in which Leaf Appeared.							
		March.	April.	May.	June.	July.	Aug.	Sept.	Oct.
I. ..	O	87	115	142	164	155	173	167	138
	N	95	127	146	179	180	177	198	149
	P	79	100	146	195	191	266	222	195
	K	89	100	142	190	195	229	232	191
	NP	76	85	122	162	172	188	184	193
	NK	97	129	153	182	225	249	252	222
	PK	83	89	134	173	194	194	225	212
	NPK	89	102	129	152	165	187	186	123
II. ..	O	95	115	132	189	219	245	218	184
	N	84	121	129	170	194	220	208	165
	P	81	96	128	152	177	204	196	169
	K	80	120	152	227	202	253	228	204
	NP	73	92	131	168	172	145	178	159
	NK	86	108	147	207	203	238	217	192
	PK	74	95	124	150	179	169	170	163
	NPK	80	103	147	198	205	227	212	184
III. ..	O	82	117	138	182	197	243	216	177
	N	82	123	143	195	243	260	230	210
	P	85	122	159	224	276	250	217	184
	K	100	110	142	205	174	258	214	212
	NP	79	102	139	198	201	194	195	190
	NK	97	110	139	190	202	240	217	143
	PK	89	102	142	168	202	216	230	198
	NPK	85	99	146	187	197	222	210	155
IV. ..	O	85	103	133	178	281	146	184	166
	N	84	94	127	162	183	204	204	167
	P	85	85	121	135	132	155	147	146
	K	71	95	123	156	133	174	167	146
	NP	77	97	133	168	188	228	174	162
	NK	92	107	132	188	192	209	200	223
	PK	80	98	136	185	201	229	220	223
	NPK	71	93	136	182	178	199	209	196

It will be noted that there is marked uniformity throughout in respect to leaves which were produced at about the same time. The plants in Block IV were for the most part notably backward in comparison with plants in all other

blocks and it will be seen that in the early months the leaves on these backward plants were somewhat shorter lived than those on the more vigorous. It may be pointed out that the policy of removing leaves showing appreciable damage precludes the drawing of any definite conclusions concerning other aspects of longevity of leaves.

SECTION 2.

MAIN INVESTIGATIONAL STUDIES.

General.

Following the exploratory work, in the course of which much qualitative information was also obtained, an investigation was planned which had as its basis two main experiments. These consisted of a growth correlation study and a main field trial. Before describing these it is necessary to deal with a number of comparatively small, but important, points which were common to all plots used in the work.

Planting Material.—Bits taken from mature corms were used as the planting material throughout. This choice is the obvious one, for by using this class of material there is no question of age or type to be considered, as would be the case with suckers; and the bit can be cut to any desired size, so that the amount of reserves on which the plant may draw initially can be more or less regulated. All bits were cut to approximately 1½ lb. weight. The planting was on the square system, the bits being set 9 feet apart.

Leaves Measured.—The first leaves of the banana are frequently so narrow that even though the length may exceed 6 inches the photosynthetic value is obviously very limited. In view of the comparatively enormous leaf area which was known to be produced it was decided to ignore these "sword" leaves and to commence recording with the first leaf which exhibited appreciable blade size. This generally meant that the leaf had a blade about 2 inches wide before it was recorded. It may be of interest to note that suckers produced as many as ten sword leaves, though usually not more than five of these had laminae more than 1 inch wide.

Sucker Growth.—The plant in each case was allowed to carry one sucker only (Plate 6), the choice of this being made after some consideration had been given to the growth of the parent plant and more particular attention paid to the type of sucker available, its position relative to the parent, and the general growing conditions. All other suckers were removed as early as practicable after their appearance above ground.

Plate 6.
SHOWING THE ONE-SUCKER SYSTEM EMPLOYED.
(Bag covers the bunch.)

Growth Correlation Plot.

This phase of the work was designed to study the correlations between vegetative growth and the development of the plant, particularly with respect to the initiation and subsequent development of the fruit. For this purpose, 36 plants were set out and leaf measurements taken as described previously. Commencing soon after the plants had become well established, at intervals of a fortnight one plant was removed from the soil and dissected. As much information as possible was sought during these dissections but the essential objective was to discover the nature and general facts of the development of the sex organs. Certain data obtained from these plants have already been quoted.

Main Field Trial Plot.

Layout.—The field trial (Plates 7, 8 and 9) was laid out in the form of a qualitative fertilizer experiment designed to allow of interpretations of differences in growth and fruit production due to applications of sulphate of ammonia, superphosphate, and sulphate of potash. A split block design was used in the hope of increasing precision. The layout is shown in Figure 1. Each plot consisted of 16 plants arranged in a square. The outside rows served as buffers between neighbouring plots, data being taken from the four centrally placed plants only. The materials were combined in the eight possible ways and each combination was repeated four times.

For the protection of the plants under investigation, a windbreak of taller growing bananas interplanted with sugar-cane was set out on three sides (Plate 10). This was planted a little earlier than the plots and was thus always sufficiently high to protect the plot plants from strong winds, but at the same time was far enough away to preclude shading or other adverse effects.

Three cross drains emptying into a main drain adjacent to the area ensured that erosion and washing would be reduced to a minimum. Observations made during the monsoonal rain period showed that the soil throughout was well drained to a depth of at least 3 feet.

History of the Field.—The land was first brought under cultivation approximately 60 years before the experiment was begun and during the intervening years had grown in succession bananas, sugar-cane, citrus, truck crops, and grass. It has been credibly stated that banana-growing was the least successful of these enterprises.

The general appearance suggested that in the course of years there had been slight erosion, more in the nature of a sifting than true sheet erosion. This had led to the building up of a shallow alluvial shelf on the lower edge. Practically the whole of this shelf was included in Block III of the layout and the design appears to have been justified by the uniformity of growth within blocks.

Location.—The field, situated on the small plateau-like top of Buderim Mountain, is of residual red basaltic loam with a slight slope to the north. With the exception of the south-eastern side the area is surrounded by open country devoid of trees, and as the mountain rises steeply and is surrounded by low country there was no obstruction to the sunlight. On the south-eastern side, which in this latitude (approximately 26° 30′ S.) is of little account so far as sunlight is concerned, was another banana plantation; but this was too far removed to affect the experimental area in any way.

Treatments and Methods.—Applications of fertilizer were made five times each year, the times being as near the beginnings of January, March, July, September, and November as weather conditions made advisable. The amounts of each material given were:—sulphate of ammonia and superphosphate, alternate dressings of eight ounces and 12 ounces per plant; and sulphate of potash, two dressings of four ounces each, followed by alternate dressings of six ounces and four ounces. These heavy applications were used to ensure adequate amounts being in the soil and were not increased after the end of the first year as is often done with bananas. Cognizance was taken of the root distribution as described by Summerville (1939) and the fertilizer materials were placed in a band about 12 inches wide round the plant. This soil is known to fix phosphate readily and it is necessary to avoid spreading phosphatic manures over too great an area.

The whole field was planted as quickly as practicable after commencement and this operation was completed on December 1, 1938.

Plate 7.
MAIN FIELD TRIAL. (Photographed January, 1939.)

Plate 8.
MAIN FIELD TRIAL. (Photographed April, 1940.)

Plate 9.
MAIN FIELD TRIAL. (Photographed April, 1940.)

The measurements of the leaves were carried out systematically on the same day of every week; and, though for the most part data on the plant crop only are used in this report, the work was continued with the ratoon plants. In general, the cultural practices of leading banana-growers were employed. So that there should be a minimum of competition for water and nutrients, no cover crop was grown and the land was kept as free from weeds as possible, except in the very wet season when weeds were of value for holding the soil against erosion. All work on the area subsequent to planting was done by hand and the soil was not disturbed any more than clean cultivation demanded.

The records of the growth of the plants are shown in Appendix 2. As practically the whole of the postulations are based on the growth of the plant crop, data from that crop only are shown. The general trends of growth of representative plants are indicated in Figures 2-6.

Although two sets of data were obtained on many points, adequate consideration can be given only by continual cross reference. For the most part, therefore, the information is dealt with from the point of view of the investigation as a whole, rather than separately in the way it was obtained.

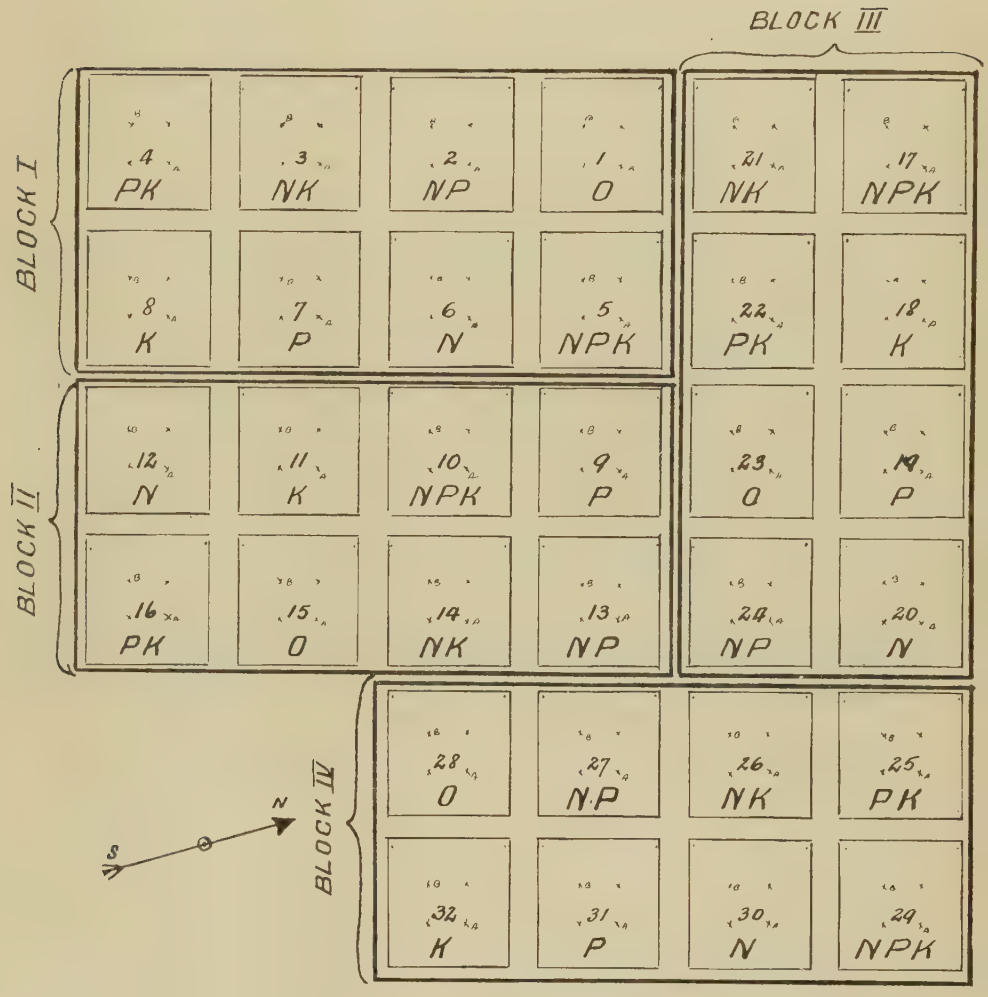


FIG. 1.—Plan of Field Trial Layout.

Leaf Production.

The growth of the plant above ground is manifested in two ways: firstly, by the extrusion of individual leaves; and, secondly, by the area of those leaves. These two criteria were examined separately.

Dealing, in the first place, with the production of successive leaves, Table 6 shows for 11 plants the average number of days intervening between the extrusion of leaves. These plants are selected for citation as they covered the widest range of vigour in the field trial plants. The dates of flowering show how the plants varied in this respect, and this is illustrated graphically in Figures 2-6.

The question was approached from the statistical point of view using rates of emergence (i.e., reciprocals of the times of emergence). The analysis of variation between months into a part that can be related to temperature variations,

Plate 10.
WINDBREAK OF MAIN FIELD TRIAL. (Photographed January, 1939.)

Table 6.

AVERAGE NUMBER OF DAYS BETWEEN SUCCESSIVE LEAVES.

Date of Flowering.	March.	April.	May.	June.	July.	Aug.	Sept.
Oct. 21	7	8	10	21	21	20	14
Oct. 22	6	10	11	19	21	20	14
Nov. 7	6	9	12	20	18	22	14
Dec. 3	7	7	8	17	21	21	14
Dec. 23	7	8	10	27	18	30	14
Jan. 3	7	8	11	21	18	21	14
Jan. 12	8	11	11	21	24	20	19
Jan. 16	7	8	11	21	24	20	19
Jan. 17	7	8	8	19	25	18	13
Jan. 30	7	10	11	19	16	13	12
Feb. 23	7	8	8	15	20	16	12

and a residual, is limited by the fact that only eight points are available. Both rates and temperature show marked trends with time and such trends must be taken into account. The trends are indicated graphically in Figure 7 which shows the calculated quadratic curves fitted to the observations. The major

trends in both rates and temperatures appear to be adequately represented by these curves. For consideration of the relation of rate and temperature the deviations from these trend lines are used.

The analysis of variance is given below:—

Analysis of Variance.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Trend—			
Linear	1	161,986·6	161,986·6
Quadratic	1	168,170·5	168,170·5
Residual Regression	1	5,703·1	5,703·1
Remainder	4	5,358·9	1,339·7
Between Months	7	341,219·1	..
Error	144	11,735·4	81·496

The residual regression term (F=69.98) is highly significant, showing that the relation between the deviations of the observed rates and temperatures from their respective trend curves accounts for a large part of the residual variation between months. The deviations are plotted in Figure 7. The significance of the remainder term in the above analysis shows that, although variations in temperature account for a significant proportion of the residual variation between months, there is still a significant amount of variation attributable either to variations in temperature not taken into account in the analysis or to some other factors such as soil moisture, &c. The explanation is more likely to be found in the latter. In March and April soil moisture, following the ample monsoonal rains, remains at a high level; it would be a little lower in May; and in June, July and the greater part of August it still would be appreciably above wilting point. From the middle of August to the end of October no rain fell; and it was not until the end of the following January that the soil moisture, at any significant depth, would be in the neighbourhood of field capacity for any length of time. The combination of soil moisture and temperature, then, appears to be largely the influence which dictates the production of the leaf. This combination points to transpiration, but so many natural phenomena are bound up with these factors in combination that a definite conclusion cannot be arrived at as to the actual determining influence. Of these phenomena the biological activity associated with the nitrogen cycle appeals as perhaps of outstanding importance.

Many score dissections were made, including those of the growth study plants, and there was comparatively little variation in the number of immature leaves within the pseudostem of plants prior to the development of sex organs. In general, the younger the plant the fewer developing leaves there were present. In well-established plants the great majority carried 11 immature leaves of large enough size to be dissected out; whilst the maximum number found was 12, and the minimum eight. There was no evidence of any tendency to spasmodic accumulation or reduction in the number being developed at any period of the year and it follows, therefore, that at any one time the extrusion of the leaves

takes place at approximately the same rate as leaf bud initiation. In view of the relation between extrusion and differentiation it seems reasonable to conclude that both are controlled largely by the same factors.

Thus it appears that leaf bud initiation is brought about by the influence of external rather than internal factors and is not to be viewed as a measure of the plane of nutrition. Of course, it cannot be wholly independent of nutrition; but it appears that, provided the internal conditions are not such as to inhibit the process, leaf buds are differentiated in response to external conditions, particularly temperature, with soil moisture probably exercising a limiting effect. This point will be referred to again in connexion with fruit bud differentiation.

Area of Leaf Produced.

It is clear from the above that if nutritional effects are to be studied the differences between plants are to be sought in the areas of the leaves and not in their numbers.

FIG. 2.—Showing Areas of Each Successive Leaf Produced by Plant.

An examination of the records of the figures showing the general tendencies of leaf growth for individual plants reveals that there is some correlation between climatic factors and the areas of leaves produced at any one time. At the same time, there is a tendency for the size of the leaf to increase as the plant ages. Age of plant, however, is obviously of secondary importance, since at any one time all 64 plants were essentially of the same age. If reference is now made to the diagrams of leaf growth shown in Figures 2-6 it will be seen that, whilst the relative tendencies at any one time are similar, the actual areas attained are widely different.

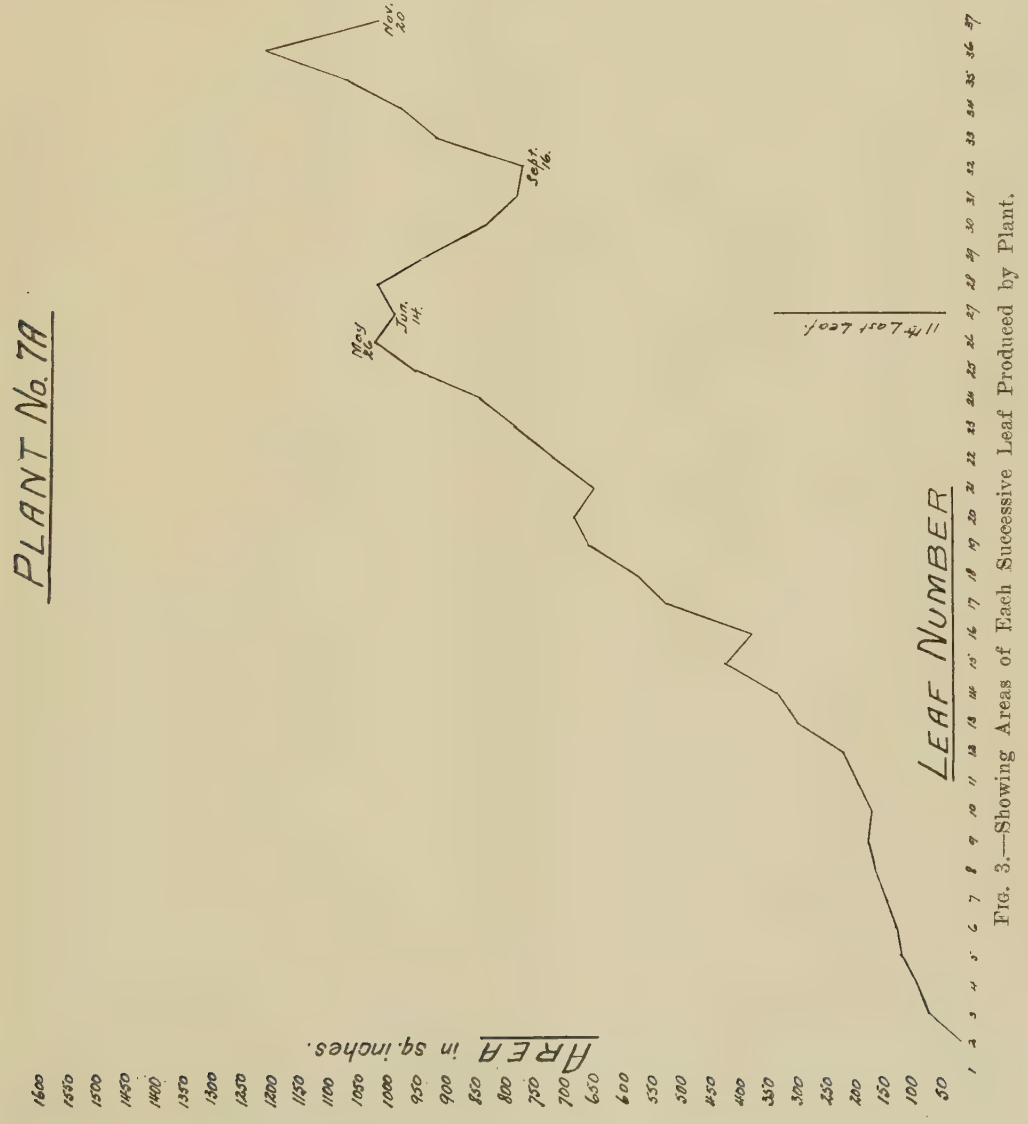


FIG. 3.—Showing Areas of Each Successive Leaf Produced by Plant.

Relation of Area Produced to Area Present.—The size of the leaf is limited, in the first place, by the meristematic activity associated with its initial differentiation; whilst, as its later growth takes place by ordinary cell division, the size attained will depend also on the metabolic activity during its development. An examination of the size in relation to the apparent photosynthetic

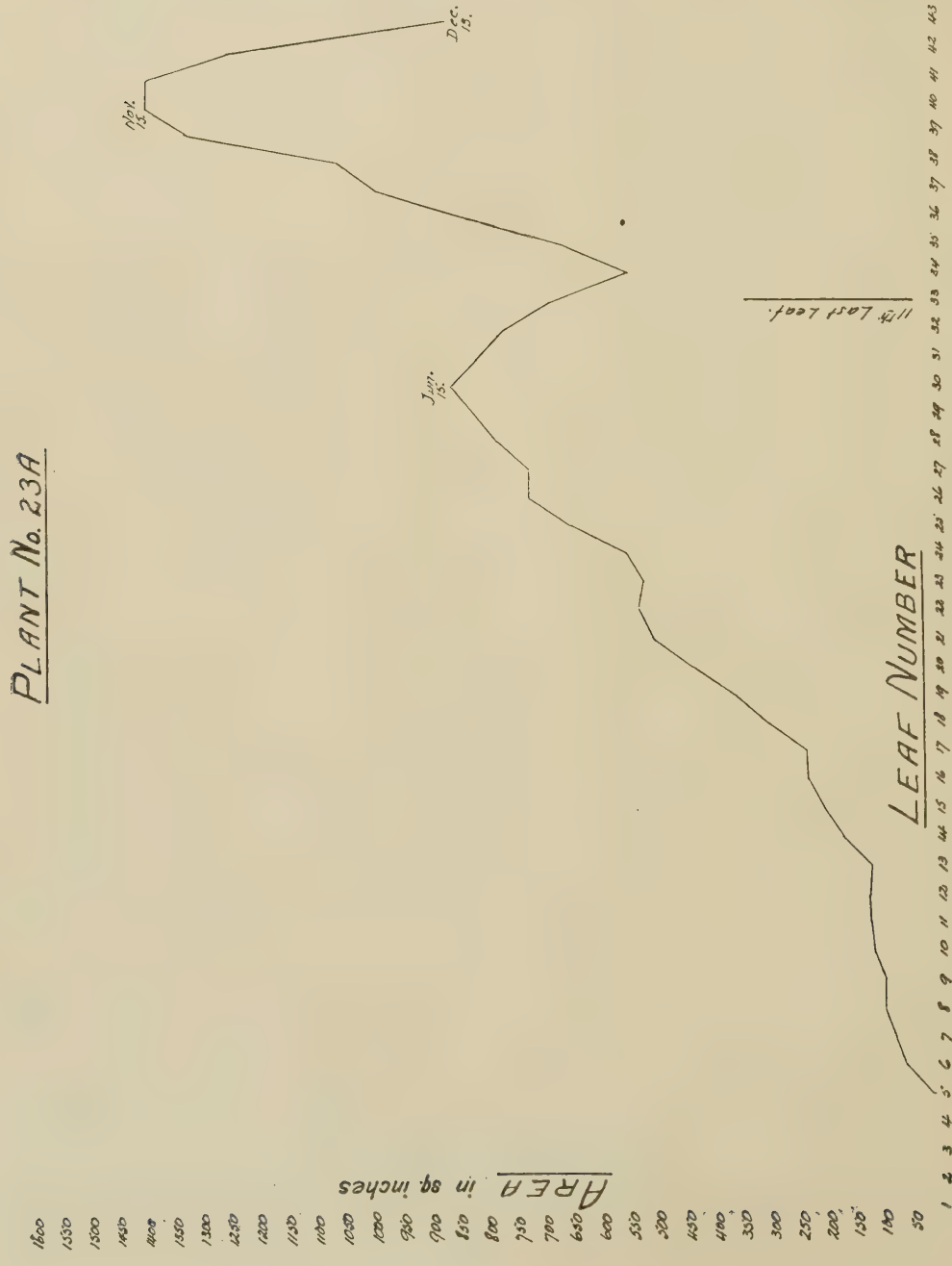


Fig. 4.—Showing Areas of Each Successive Leaf Produced by Plant.

potential might throw some further light on the measurement of that activity. The two can be compared in an approximate manner by finding the relation between area of leaf on the plant at any one period and the area produced during that period. There must, of course, be some lag between the time during

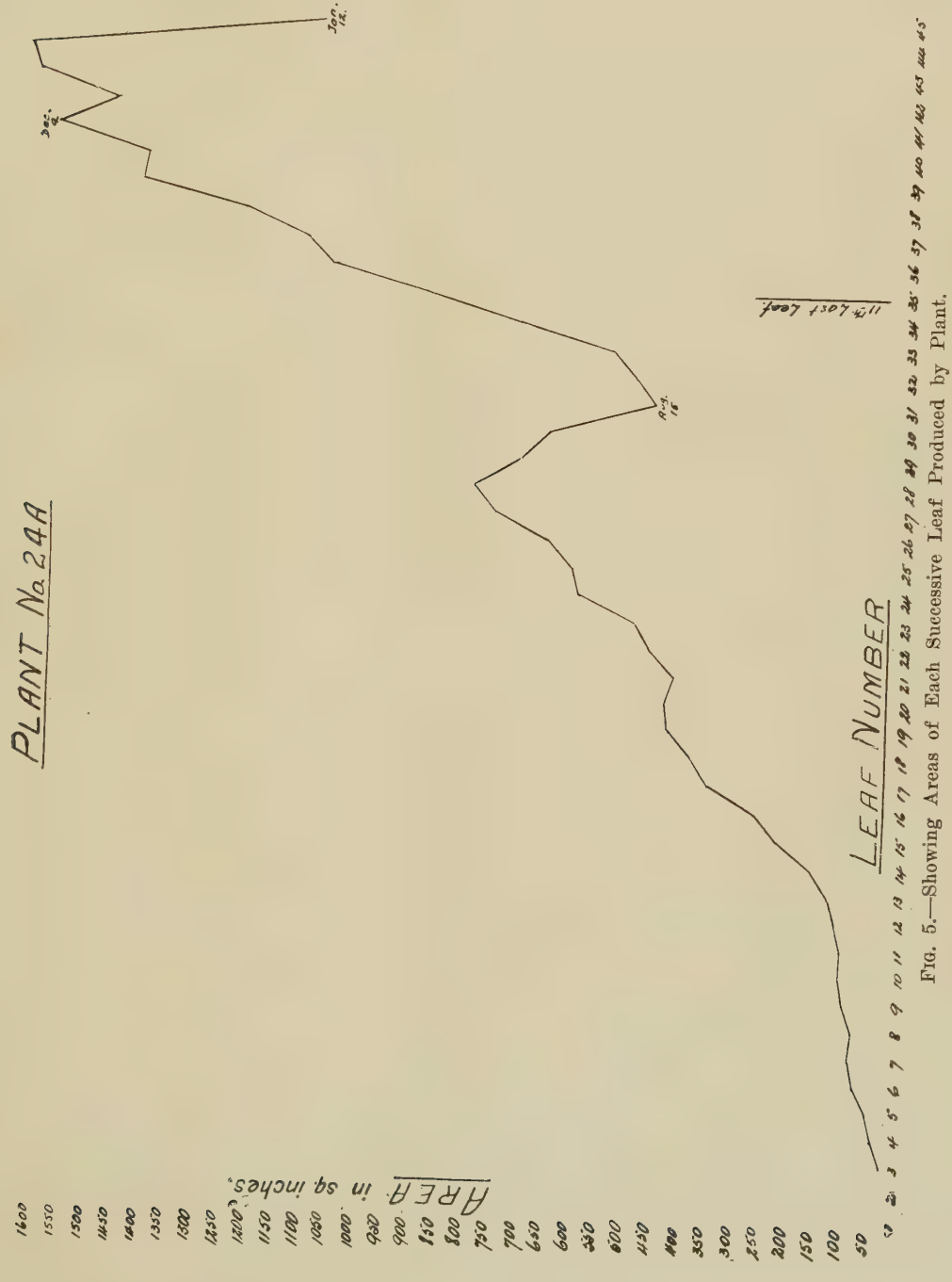


FIG. 5.—Showing Areas of Each Successive Leaf Produced by Plant.

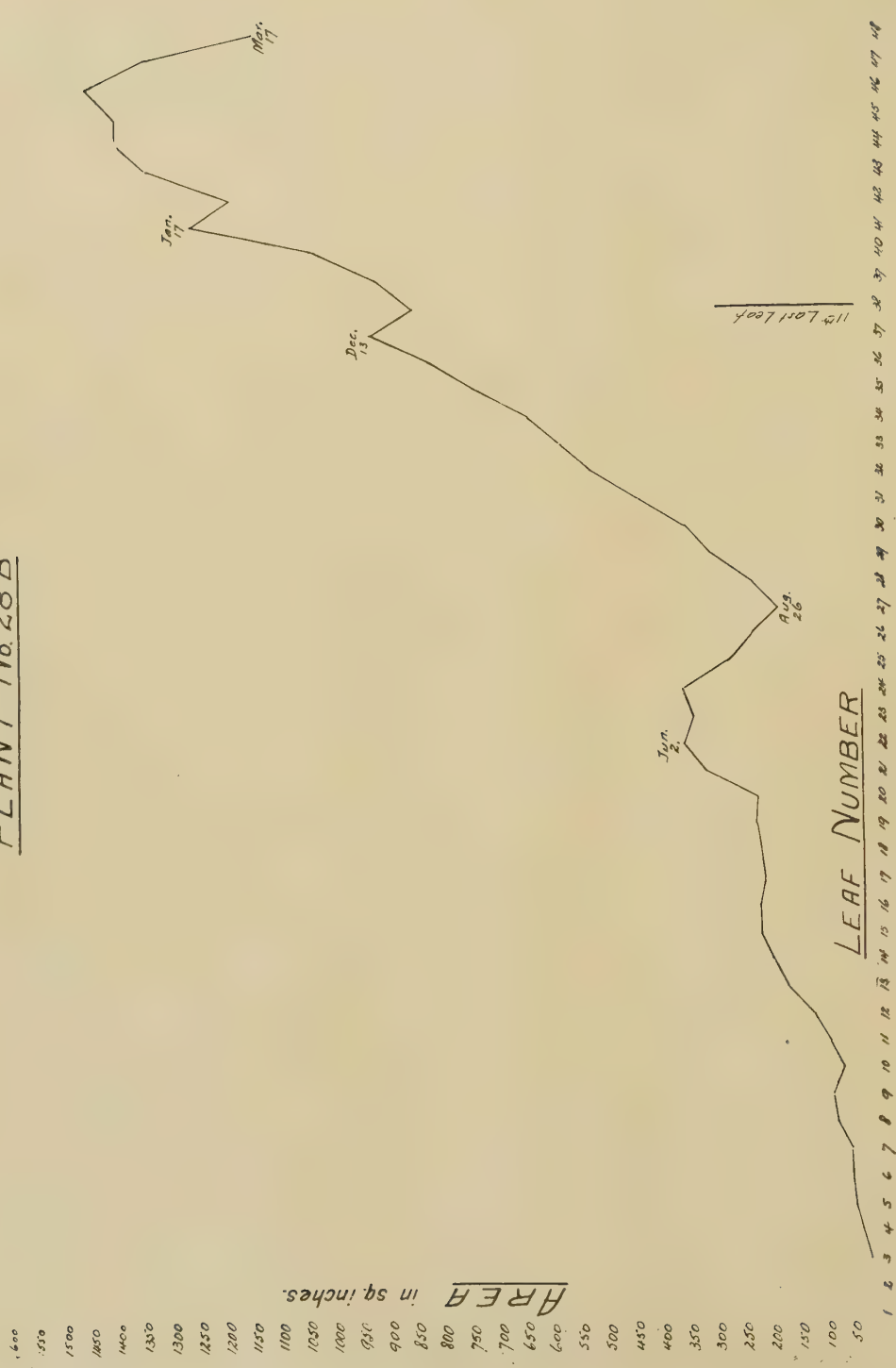
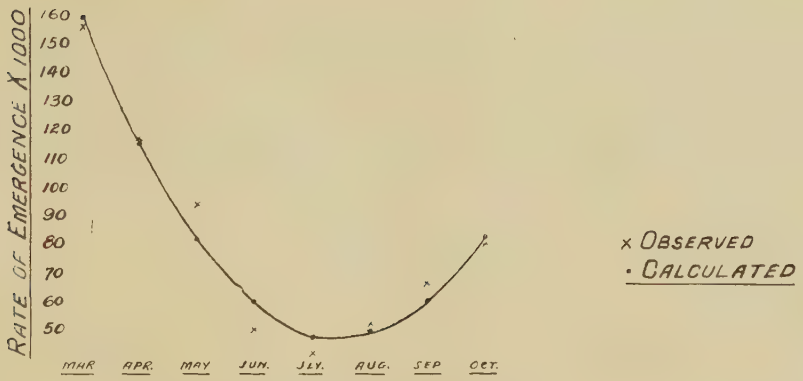
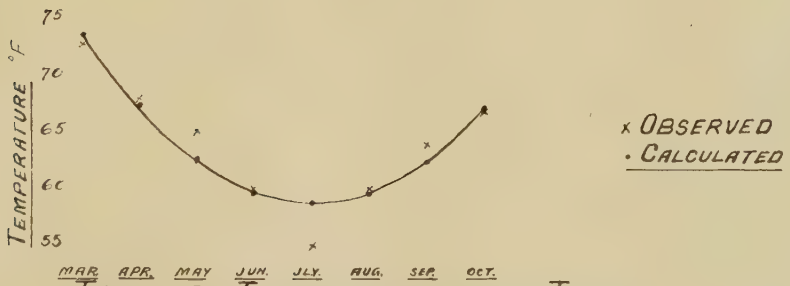


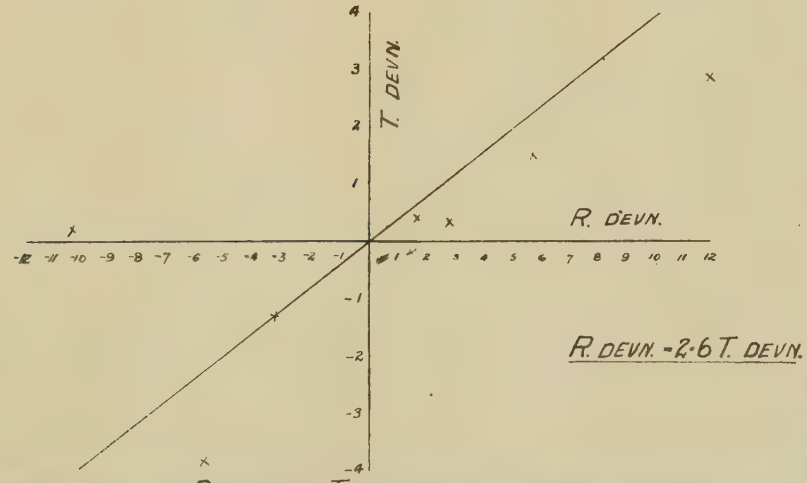
FIG. 6.—Showing Areas of Each Successive Leaf Produced by Plant.



TREND OF RATE WITH TIME.



TREND OF TEMPERATURE WITH TIME.



CORRELATION OF RATE AND TEMPERATURE AFTER ELIMINATION OF TRENDS WITH TIME.

FIG. 7.—Rate of Emergence of Leaves.

which the growth of the organ takes place and the time of its extrusion in the form of a fully matured leaf; and as there is evidence to suggest that the lag is approximately one month in certain periods the area produced is taken for the month following that in which the particular area on the plant occurred. There is no reason to assume that the lag is constant for all periods of the year, but the area on a plant does not fluctuate violently (see Figure 8) and any error

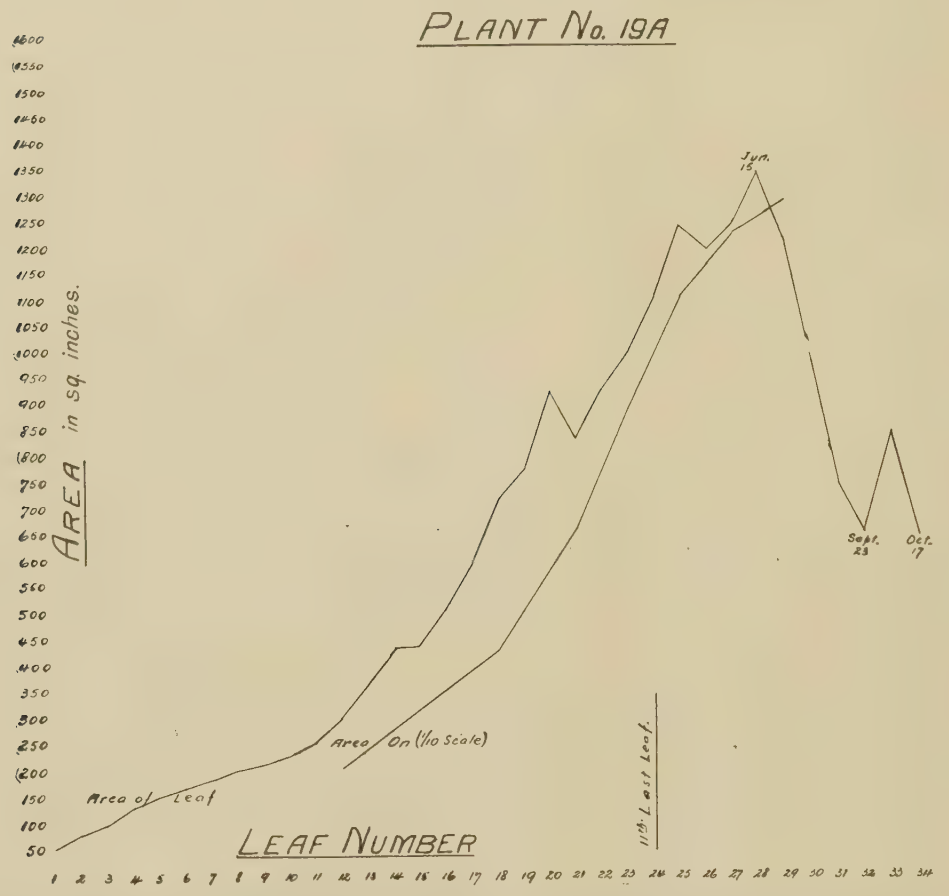


FIG. 8.—Showing Areas of Each Successive Leaf Produced by Plant and Area Retained on Plant at Time of Emergence of Each Leaf.

thus introduced would consequently not be large and would not destroy the value of comparison between plants. The relationship for 18 plants is shown in Table 7. It will be seen that reading down the table, or in other words reducing the climatic variation to a minimum, there is a fair degree of uniformity of ratios between plants. Further, if the ratios in the various months are considered in conjunction with the mean temperatures, as shown in Figure 12, it will be seen that temperature is almost certainly a limiting factor. A close scrutiny of the figures, however, reveals many exceptions to the general uniformity and further evidence is needed before any conclusions can be drawn.

Table 7.

AREA OF LEAF ON PLANT

AREA PRODUCED

Plant No.	Month in which Area Appeared.							
	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.
1B	6·1	6·8	5·9	10·5	13·8	17·0	9·8	6·7
2A	5·7	5·6	5·4	8·8	10·0	13·4	11·2	8·2
2B	5·0	6·3	7·6	9·2	11·6	14·5	12·9	10·7
3A	5·9	7·1	8·4	10·2	10·0	16·5	10·6	10·7
4A	5·2	6·0	8·2	9·4	10·7	11·8	12·2	8·7
4B	5·8	7·0	8·4	9·5	11·0	14·3	13·1	12·2
5A	6·5	7·1	8·1	9·2	10·1	12·6	9·4	7·8
5B	7·2	6·8	7·1	8·2	10·0	12·8	8·0	7·2
6A	5·9	7·3	8·7	9·4	12·0	11·3	9·0	6·7
6B	6·4	7·6	7·9	10·1	10·5	13·9	15·0	10·0
1A	7·1	7·6	8·7	11·1	12·1	18·1	15·2	9·2
3B	6·5	8·1	8·6	10·4	11·7	15·2	13·1	..
18A	6·3	7·7	9·2	10·5	12·6	18·1	12·1	10·1
14B	6·6	7·7	8·0	9·9	11·0	15·3	14·1	11·0
19A	6·4	7·7	9·5	10·6	11·9	16·1	18·0	..
22A	6·2	7·0	8·2	9·8	11·7	13·5	13·3	8·4
27B	6·8	7·1	8·0	9·4	10·8	13·2	12·3	7·4
12B	5·9	7·3	8·1	10·8	14·9	10·6	10·5	8·0

Effect of Defoliation.—In an effort to throw further light on the question of determination of leaf size, two well-established plants were selected and defoliated and from that time onwards the leaf blades were removed within 12 hours of complete unfurling of each in turn. The removals were commenced in September and continued until about the end of October. At the same time two comparable neighbouring plants were also kept under observation but these were allowed to retain all their foliage in the normal way. The areas in square inches of new leaves unfurled after the time of defoliation were as follows:—

—	Defoliated Plants.		Normal Plants.	
	A.	B.	C.	D.
1st leaf	138	115	117	61
2nd leaf	166	132	148	72
3rd leaf	166	150	175	79
4th leaf	155	144	205	104
5th leaf	124	158	220	98

The leaves are numbered in the order they appeared after time of defoliation.

The experiment had to be discontinued at this stage; for the defoliated plants were showing other effects, notably their inability to force the new leaves clear of the throat, the petioles apparently not being able to elongate to their normal dimensions. The plants were then allowed to retain the leaves they produced after this time in the hope that some information might be gained as

to the longer range effects of temporary defoliation. However, the treated plants failed to respond in the desired manner. Each produced only one leaf whilst the check plants produced six. This last information can be taken as suggestive only, since the banana weevil borer was found to have made considerable inroads on the treated plants by that time.

The information is reduced in value owing to the small number of plants employed, but it does suggest that there is considerable lag in the utilization of carbohydrate in the manufacture of leaf tissues and that the area of leaf produced at any particular time is not necessarily consequent on the photosynthetic activity during the period just preceding the development of its greatest mass. The question could not be approached from the opposite angle, by reducing the amount of storage tissue at the disposal of the plant at a particular time, since the removal of a considerable amount of this can be done only with the concurrent reduction of other essential plant parts, particularly the roots. Apart from the size of the leaf, the observations show that when the photosynthetic activity is markedly reduced the metabolic processes involved in the synthesis of proteins are not immediately violently disturbed.

Relative Increase in Leaf Area.

The question of growth was then approached from the point of view of increase in leaf area; and as a trend with time was observed, as has been pointed out, the problem was first attacked through relative increases. It is to be noted that five plants were rejected from these calculations because factors outside the experiments entered into the question and adversely affected the plants. The trouble in three of the five was found to be due directly to the depredations of the banana weevil borer, whilst in the other two inferior planting material was believed to have been used.

The first application of artificial fertilizer was made in early January, and was followed by others in March, July, September, and November. In Table 8 are shown the relative increases in the leaf area produced by the individual plants, the figures being the percentage increase for each month over the total at the end of the previous month. A graphical representation of the data is given in Figure 9, whilst Table 10 summarizes figures for the first two months.

Table 8.

PERCENTAGE INCREASE IN LEAF AREA DURING EACH MONTH.
(Original Plants).

Treatment.	Plant No.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
O ..	1A	71	67	49	28	12	8	8	12	19	23	25
	15A	131	114	50	22	16	8	9	14	18	21	28
	15B	124	148	43	23	11	7	10	4	16	..	..
	23A	85	111	55	30	15	11	9	14	19	23	..
	23B	89	107	51	31	14	10	8	11	15	..	..
	28A	122	95	47	27	17	9	10	12	18	23	19
	Av.	102	107	49	27	14	9	9	13	18	23	24

Table 8—continued.

PERCENTAGE INCREASE IN LEAF AREA DURING EACH MONTH.
(Original Plants).

Treatment.	Plant No.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
N ..	6A	89	92	51	33	17	10	10	12	19	21	26
	6B	66	82	47	33	13	11	8	12	18	21	23
	12A	99	136	49	33	14	14	6	8	14	..	..
	12B	86	111	39	32	10	9	10	12	15	21	28
	20A	111	111	58	24	9	8	8	8	..	..	..
	20B	102	114	42	28	12	11	7	11	15	..	..
	30A	160	135	49	33	14	10	7	10	19	24	19
	30B	156	109	58	38	12	11	11	14	16	25	27
	Av.	109	111	49	32	13	11	8	11	17	22	25
P ..	7A	105	109	42	34	15	10	9	18	8	..	..
	7B	80	82	52	35	17	9	11	14	17	35	28
	9A	110	114	60	41	10	9	8	12	20	25	25
	9B	36	146	75	40	20	9	10	15	21	23	28
	19A	116	86	46	22	10	6	7	12	..	..	..
	19B	118	96	42	32	15	5	7	10	..	..	..
	31A	68	72	57	38	12	10	10	12	18	24	26
	Av.	90	101	53	35	14	8	9	13	17	24	27
K ..	8A	92	119	39	18	15	9	9	10	17	21	21
	8B	86	120	47	38	19	3	15	12	17	23	29
	11A	149	124	41	29	15	11	12	10	17	..	..
	11B	133	103	39	36	15	8	9	11	15	..	..
	18A	145	106	52	30	10	7	8	8	16	..	..
	18B	85	108	55	30	11	9	7	4	21	..	..
	32B	142	106	38	27	10	19	2	9	13	23	24
	Av.	120	112	44	30	14	9	9	10	16	22	25
NP ..	2A	93	156	30	51	7	32	11	18	22	15	36
	2B	107	186	75	44	23	12	10	13	16	20	..
	13A	86	108	48	34	14	11	7	12	22	25	31
	13B	88	98	61	37	18	9	9	13	21	34	29
	24A	96	115	51	35	19	10	10	15	13	28	28
	24B	136	126	53	28	13	9	8	12	..	..	..
	27A	79	100	44	29	11	10	7	10	17	25	26
	27B	76	83	48	31	12	11	8	12	18	21	21
	Av.	96	121	51	36	15	13	9	13	18	24	29
NK ..	3A	121	123	63	36	16	10	11	11	15	17	..
	3B	82	133	30	35	16	10	8	11	..	..	..
	14A	145	120	57	33	12	10	9	10	..	..	..
	14B	132	83	44	30	17	8	10	11	8	..	..
	21B	99	102	52	29	17	9	11	8	16	..	..
	26A	122	133	68	42	14	12	9	20	20	27	31
	26B	101	106	47	35	12	10	13	8	17	22	..
	Av.	114	114	52	24	15	10	10	11	15	22	31

Table 8—continued.

PERCENTAGE INCREASE IN LEAF AREA DURING EACH MONTH.

(Original Plants).

Treatment.	Plant No.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
PK ..	4A	142	157	70	41	14	12	10	7	19	21	..
	4B	180	110	52	34	15	12	8	12	13	..	..
	16A	100	139	57	42	19	11	10	16	18	26	27
	16B	83	106	51	40	17	11	10	15	19	26	27
	22A	125	89	52	28	12	9	8	11	15	..	..
	22B	94	112	40	31	13	10	9	12	15	17	..
	25A	141	140	31	31	10	7	1	19	18	23	25
	25B	112	148	50	27	14	9	10	11	9	..	..
	Av.	122	125	50	34	14	10	9	12	16	23	26
NPK ..	5A	99	93	57	32	13	10	10	14	18	26	23
	5B	66	63	42	35	15	10	9	18	16	31	32
	10A	168	152	60	41	20	10	9	13	20	26	12
	10B	110	115	44	33	12	9	9	10	..	..	..
	17A	112	126	50	35	15	8	7	12	17	24	19
	17B	130	113	55	32	16	9	8	10	15	..	..
	29A	164	119	68	33	13	11	8	13	20	27	21
	29B	98	103	45	36	16	8	8	11	15	..	..
	Av.	119	110	53	35	15	9	9	13	17	27	21

Table 9.

PERCENTAGE INCREASE IN LEAF AREA DURING EACH MONTH.

(1st Ratoon Plants.)

Plant No.	Dec.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.
1A ..	..	275	68	51	33	3	9	5	8	8
1B ..	..	..	..	327	119	46	24	15	20	22
2A ..	487	220	121	68	28	13	12	7	7	9
2B ..	179	113	82	20	20	..	..	..	..	..
3A ..	300	170	58	32	19	11	7	5	..	..
3B ..	..	198	63	44	23	11	6	6	5	7
4A ..	..	171	55	45	28	13	9	8	9	4
4B ..	..	177	100	51	35	14	9	7	5	9
5A ..	..	..	..	..	138	34	19	12	10	20
5B ..	..	..	126	44	31	18	11	10	4	18
6A ..	..	..	494	174	42	25	13	7	12	11
6B ..	..	216	69	36	17	9	9	4	8	10
7A ..	..	155	107	50	27	19	10	8	6	10
7B ..	..	173	87	60	23	14	8	5	7	9
8A ..	457	164	87	56	22	13	9	5	7	6
8B ..	..	..	203	107	39	15	12	9	7	10
9A ..	304	127	79	40	19	12	7	6	6	9
10A ..	..	217	73	39	23	13	8	6	6	..
10B ..	354	141	66	40	18	10	5	5	4	..
11A ..	261	137	45	38	24	10	14	..	..	..
11B ..	..	217	75	40	11	8	..	..	..	..

Table 9—continued.

PERCENTAGE INCREASE IN LEAF AREA DURING EACH MONTH.

(1st Ratoon Plants.)

Plant No.	Dec.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.
12A ..	530	121	90	59	24	15	7	6	5	..
12B ..	..	..	116	46	27	12	8	6	6	10
13A ..	..	220	101	54	17	14	8	7	6	9
13B ..	..	..	135	64	25	13	9	7	7	7
14A ..	..	163	88	37	22	14	7	7	..	..
14B ..	366	147	72	37	19	11	6	9	..	..
15A ..	..	..	..	..	..	162	26	15	7	8	9
15B ..	512	165	79	41	21	14	7	5	..	..
16A ..	..	..	182	105	39	18	11	6	7	9
16B ..	..	..	203	185	40	17	14	9	8	9

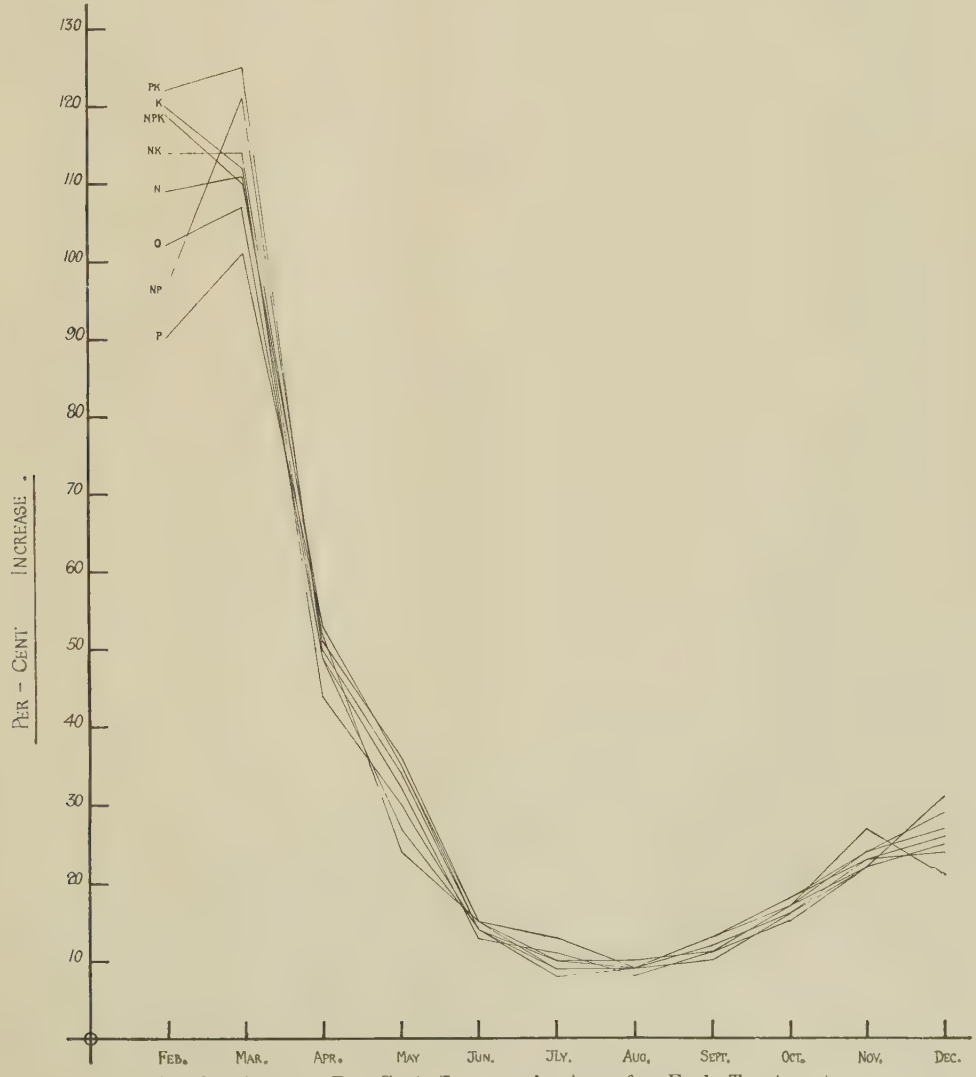


FIG. 9.—Average Per Cent. Increase in Area for Each Treatment.

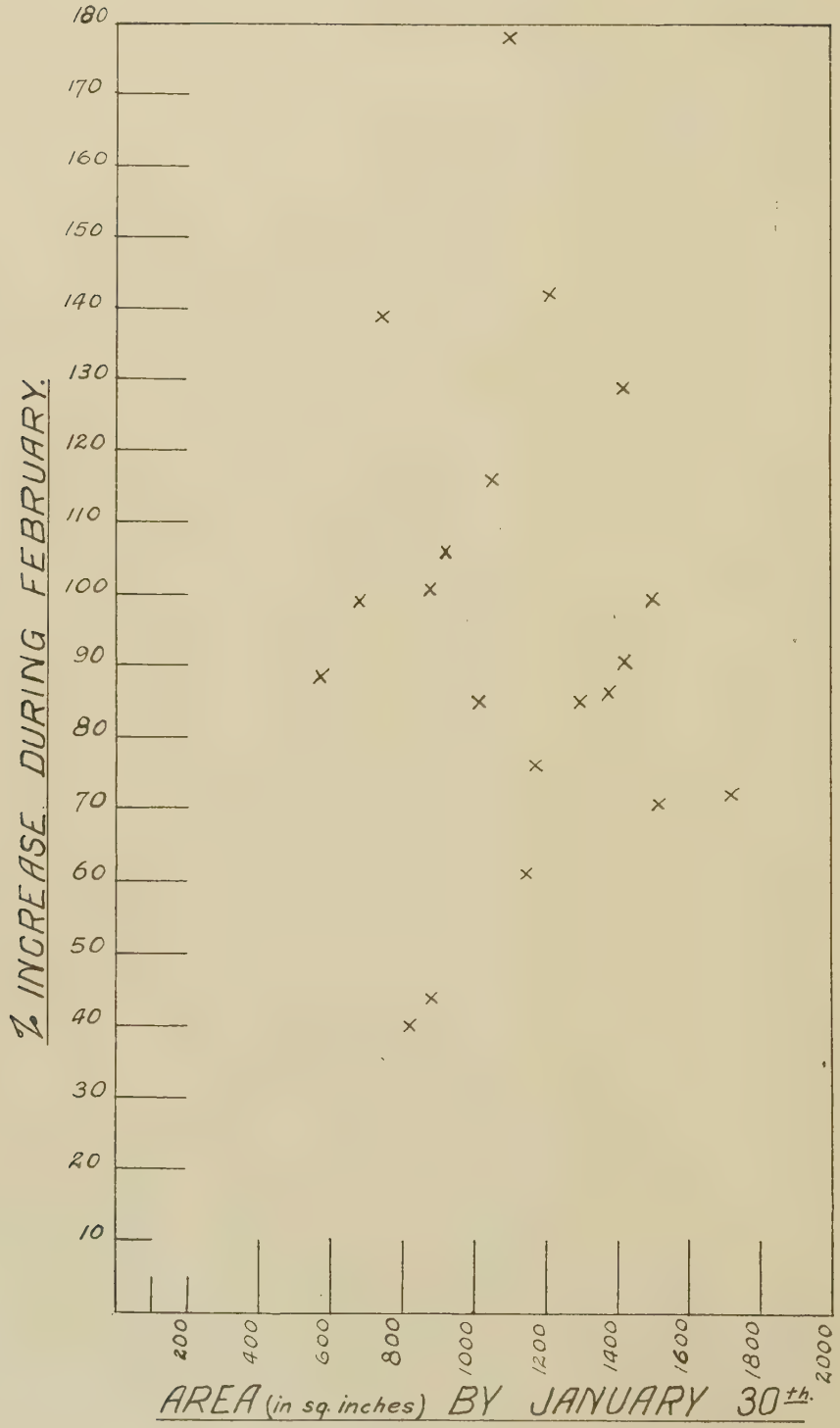


Fig. 10.—Showing Relation of Increase in Area to Initial Value.

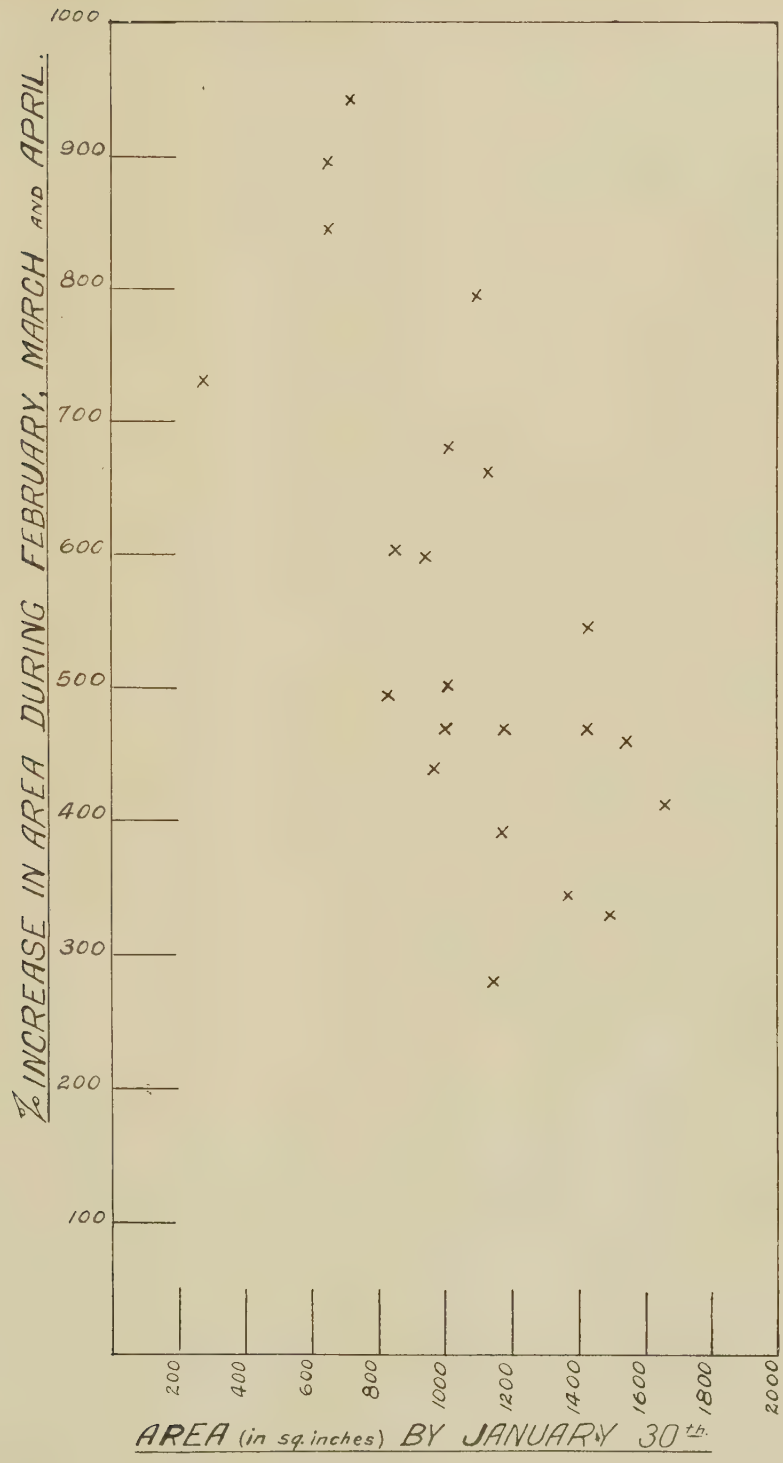


FIG. 11.—Showing Relation of Increase in Area to Initial Value.

The scatter diagrams constituting Figures 10 and 11 show that the increases are not correlated with original size.

The outstanding feature is the remarkable similarity in the relative increases in leaf area from April onwards. An analysis of variance (Appendix 3) shows that, whilst *in the very early stages of growth significant increases were associated with the presence of added potash, no significant differences are found after March* though, of course, no statistical analysis is necessary after April.

Table 10.

Summary.

Percentage Increase in Area, January–February.

	P_0	P_1	K_0	K_1	Means.
N_0	211·8	204·8	194·7	221·9	208·3
N_1	210·6	206·8	201·9	215·6	208·7
Means	211·2	205·8	198·3	218·8	208·5

	K_0	K_1
P_0	205·3	217·2
P_1	191·3	220·3

Analysis gave F for K 5·01, which is significant. s.e. per plot 25·87 = 12·41 per cent. G.M. "Sampling" error per plot 15·94 = 7·64 per cent. G.M.

Nutritional Interpretation.—There would appear to be from the point of view of nutrition but one possible interpretation of the figures concerning relative increase, viz., *that the intrinsic rate at which the plant can use certain minerals is determined very early in the history of the plant.* It must be remembered that the treatments were given at five different times throughout the year; but in no instance is there the slightest evidence of any effect on leaf area, and, therefore, presumably none on any other phase of growth, after the end of the third month, whereas before that time statistically significant differences occurred.

Much work has been done on the uptake of nutrients by plants of different ages and it is of interest to note that Gericke, as reported by Miller (1938, p. 371), working with wheat found that removal of the source of potash when the plants had reached the age of four weeks did not appreciably affect the amount of growth which the plants subsequently made and that larger amounts of straw were obtained when the supply of phosphorus, magnesium, or sulphur was removed from plants one month old. Brenchley (1920) and other workers have obtained similar results. There is no evidence from the present figures that the total requirement of potash is taken up by bananas in this early period but merely that the rate at which the plant can subsequently use this element, and presumably other mineral nutrients, is determined at that time. The two points could not be demonstrated concurrently, for the one necessitates continuous supply whilst the other requires starvation after a certain interval. It

may be pointed out that over the longest period between applications, viz., March to July, the potash-treated plants maintained their relative increase in comparison with the remaining plants though the amount of potash supplied up to that time was only eight ounces. Further, bananas are reputed, and apparently on fairly good grounds, to deplete the soil of some essential food very rapidly; but the plants which received no artificial fertilizer, as well as those which apparently derived no benefit from the treatment they received, all went forward at the same relative rate.

The figures for the ratoon plants are not so readily capable of analysis. The suckers are produced at various times and the plant remains in organic connexion with the parent corm for a considerable period: there is no way of assessing the value of that connexion to the offset. The true age of the sucker is also in doubt; for when desuckering is carried out the growing point is not necessarily destroyed and it is possible, and in fact very probable, that the sucker which is finally allowed to persist as the follower was cut back earlier because the parent plant was not far enough advanced, or the general conditions unsuitable, at the time it first showed through the soil. Thus the ratoon plants are not strictly comparable. Nevertheless, the same tendency to relative increase

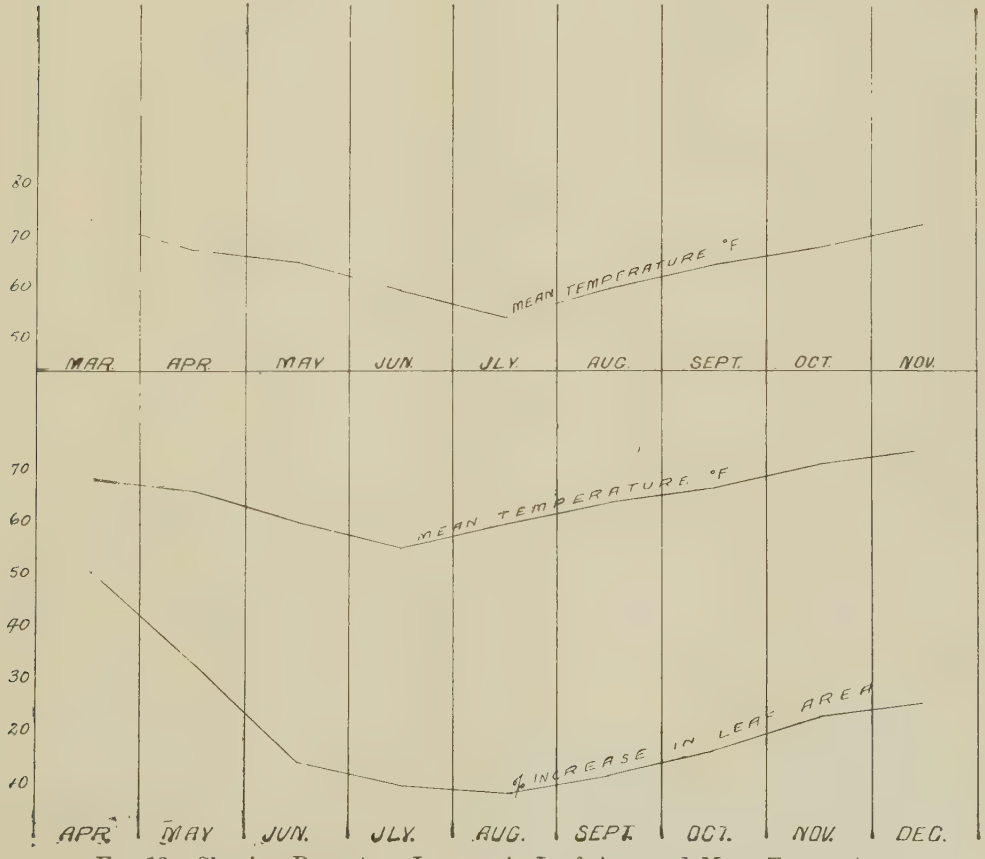


FIG. 12.—Showing Percentage Increase in Leaf Area and Mean Temperature.

at a uniform rate after a few months' growth is evident, irrespective of initial differences. For example, Plant 1A, which commenced producing leaves towards the end of November, increased 275 per cent. in January, 33 per cent. in April, 5 per cent. in July, 8 per cent. in August, and 8 per cent. in September; whilst Plant 15A, which commenced leaf production late in February, increased 162 per cent. in April, 7 per cent. in July, 8 per cent. in August, and 9 per cent. in September. The figures for half the first ratoon plants are shown in Table 9 (pages 34 and 35).

In Figure 12 are shown the mean increases in leaf areas per month from April onwards for all 64 of the original plants. In the lower portion of the graph are shown the mean monthly temperatures for the same period. As has already been indicated, there is a lag in response by the plant to the climatic conditions; and, in order to bring out that lag more clearly, in the upper half of the figure the mean temperatures are arranged to allow for a lag of one month. There is, of course, no reason to assume that the lag is constant throughout the year.

Efficiency in Growth.

The conclusion which has been reached concerning the early uptake of mineral nutrients is a most important one from the points of view of both experimentation and farming practice and it is of importance to throw as much light on the question as possible. An attempt to examine the question was carried out by the use of the concept of growth proposed by Blackman (1919) as being mathematically allied to the rate of increment of capital increasing at compound interest. Fisher (1921) states that this is the correct measure for the mean value of relative growth rate over any period, long or short.

In examining the efficiency with which the various plants grow there are two established points that must be borne in mind. In the first place, it is apparent that the size of the leaf produced at any one time is an index of the general metabolism within the plant. Secondly, though the area of leaf may vary tremendously as between one plant and another, the rate at which individual leaves are budded is virtually constant for all individuals of the same age at any one time. This means that, though the periods for which the meristems are active in laying down the initials of the leaf are nearly the same for all plants at any one time, the final results of that activity may be very different.

Blackman, and others who have used the compound interest concept, worked with dry weights of plants, whereas here leaf areas are being examined, so that the formula used became

$$A_1 = A_0 e^{rt}$$

where A_0 is the area produced by an initial time, A_1 the final area attained, r the rate or an index of "efficiency of the plant as a producer of new material," t the time, and e the base of natural logarithms.

Where the plant is grown from seed an obvious original point is indicated either in the seed weight or in the size of the cotyledons. In the case of the

banana, however, no such well defined point is apparent. It was decided to work, in the first place, with the area at January 31 as A_0. The formula was then applied and it was found that the great majority of plants gave an approximately equal value for r. The only plants which deviated to an appreciable extent were those which had an abnormally low value for A_0. The normal value for this initial area was in the vicinity of 1,000 square inches and an examination showed that the backward plants had all attained areas of about that size by the end of February. The abnormal plants were then re-examined using the end-of-February total. It was found that these plants then gave results consistent with those of the normal plants. Table 11 shows the value of r expressed as percentage increase per day between the attainment of approximately 1,000 square inches of leaf and the cessation of foliage production. It will be seen that the average efficiency index (r) is virtually constant for all plants; it is seemingly conferred by virtue of the genetical constitution.

Table 11.

VALUES OF r EXPRESSED AS PERCENTAGE INCREASE PER DAY.

Plant No.	r	Plant No.	r	Plant No.	r	Plant No.	r
1A ..	·0080	9A ..	·0097	16B ..	·0091	24B ...	·0104
2A ..	·0099	9B ..	·0094	17A ..	·0095	25A ..	·0102
2B ..	·0104	10A ..	·0090	17B ..	·0103	25B ..	·0090
3A ..	·0102	10B ..	·0098	18A ..	·0090	26A ..	·0091
3B ..	·0093	11A ..	·0101	18B ..	·0088	26B ..	·0091
4A ..	·0110	11B ..	·0095	19A ..	·0087	27A ..	·0084
4B ..	·0109	12A ..	·0099	19B ..	·0090	27B ..	·0084
5A ..	·0092	12B ..	·0086	20A ..	·0094	28A ..	·0092
5B ..	·0084	13A ..	·0091	20B ..	·0094	29A ..	·0084
6A ..	·0089	13B ..	·0097	21B ..	·0091	29B ..	·0091
6B ..	·0080	14A ..	·0108	22A ..	·0092	30A ..	·0105
7A ..	·0091	14B ..	·0091	22B ..	·0089	30B ..	·0102
7B ..	·0088	15A ..	·0094	23A ..	·0091	31A ..	·0083
8A ..	·0086	15B ..	·0094	23B ..	·0092	32B ..	·0090
8B ..	·0092	16A ..	·0091	24A ..	·0097	..	..

The question of differences in absolute leaf production then remains to be determined. The banana does not flower at a particular time of the year and differences are to be sought in the time taken for the completion of the area and in the area itself. The constancy of r is obviously brought about by the fact that normally A_1 increases as t increases. *The total growth is thus not a function of temperature or other external factor,* a result which is in keeping with that obtained by Gregory (1928a) working with the cucumber.

The interpretation of the data is based on the deduction that the first period in the growth of the plant represents a stage during which the apical meristem is being developed. It appears that the rate of development of the meristematic organization, or its size, depends on the availability of nutrients at the appropriate time, and from the time of completion of this tissue all plants complete their growth at a like average rate as measured by r in the formula.

It should be pointed out that this value of r is calculated over a considerable period and that the growth rate is not constant during that period. Therefore, the only valid conclusions which can be drawn from these data must deal with a like period.

The completion of the meristematic organization is associated with the attainment of an area of leaf, or in other words with an amount of growth, rather than with time. The differences in absolute amounts appear to be brought about largely by the sizes of the meristems rather than by the periods required for the laying down of that tissue.

Taking plants 11B and 15A, for example, the following data may be considered:—

	11B.	15A.	Difference.
1,000 sq. in. attained	Jan. 20	Feb. 1	11 days
Completed growth	Nov. 13	Jan. 16	50 days
Average value of r	·0095	·0094	·0001
Total area of leaf (sq. ins.)	22,700	28,120	5,380

From Table 12 it will be seen that the percentage increases in leaf area in each case in each month after February show no significant differences and thus there can be no real differences in metabolism between the two plants. If it is taken that both plants shown an average efficiency index of ·009 this means that if both start with the same amount of meristem then 11B must have accumulated that amount approximately 30 days earlier than did 15A. Such a proportional difference in the length of the periods of development is scarcely conceivable. On the other hand if the meristem of 11B were approximately 1·3 times the size of that of 15A the differences between the plants are explicable. From such considerations it is concluded that, whilst there may be small differences brought about by time required to complete the organization, the differences between plants is due very largely to the size of those organizations.

The values of r for periods commencing after the completion of the first stage of growth remain parallel in different plants, while the plants remain comparable with respect to their development; as will be seen from Table 12, in which are shown the values of r for different periods in respect to four plants.

Table 12.

Values of r for Various Periods.

Plant No.	1,000 Sq. In.	Feb. 28.	Mar. 31.	April 30.	May 31.	June 30.	July 31.	Aug. 31.	Sept. 30.	Oct. 31.	Nov. 30.
	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
11B	95	73	52	45	31	33	42	42	36	24	..
8B	90	81	63	56	49	48	57	58	61	64	63
23B	92	77	57	45	37	33	36	42	36	48	..
15A	94	77	51	50	47	48	52	58	60	62	57

The duration of the periods is from the date indicated to the completion of foliage development.

It will be noted that the values of r commence to diverge in March, but the divergence is in two sets. Plants 11B and 23B remain similar until September whilst 8B and 15A also remain similar to one another until just before completion of growth of leaves. *The key to the differences between the two sets is to be found in the dates at which flower bud development took place.* This marks the end of a stage in the development of the plant, and the relevant calculated dates as shown in Table 15 (pages 69 and 70) are May 20 for 11B, May 25 for 23B, September 9 for 8B, and September 12 for 15A. The drop in index of efficiency is particularly noticeable in the two early budding plants but is less obvious in the other two as the budding in those cases more or less synchronized with the advent of more propitious growing conditions.

The evidence from a study of the efficiency index indicates that variation in the growth of different banana plants is due almost wholly to the development in the very early stages. This development appears to be associated with size of the meristematic organization then laid down, and the amount of this tissue then developed determines both the area of leaf finally attained and the length of time required for its attainment. These two are by nature inextricably bound together. Environmental factors still play a very important part in growth and development; and whilst the meristem of one plant may be such that, under say July conditions, a leaf of 1,000 square inches is produced as against one of 500 by a second individual, the latter plant may still be capable of producing a leaf of 1,000 square inches in November. The modifying effect of environment is thus very considerable and it follows that *the size of the meristem chiefly influences the period required for the completion of leaf production and not the total area attained.*

The fruit of the banana is developed from the same region as the leaves and as will be shown later the two, considered as products of growth, are affected in much the same way by environmental influences. Environment has a continuous and far-reaching influence; and though not specifically so interpreted much of the work recorded in this paper is a study of the effect of environment at a particular time on the accumulated results of environment up to that time. The apical meristem is the medium through which the effect of the combination is manifested; and the absolute size of the effect, at any one time, appears to be proportional throughout life to the size of the meristematic organization laid down very early in the life of the plant.

The position may be summed up as follows:—The meristematic potential of the plant is laid down early in the life of the plant in response to the uptake of nutrients. When this laying down is complete the ability of the plant to utilize nutrients for the production of other tissues is automatically fixed. Environment may influence actual size during subsequent growth but the rate is a function of the meristem and size is automatically adjusted by the time factor. Thus the period of formation of the meristematic tissue is a vital one in the history of the plant.

SECTION 3.

FLOWER BUD INITIATION.

General Considerations.

If the development of the plant is to be traced with any degree of completeness it is necessary to have some information on the time of the change from purely vegetative increase to production of the flowers and fruit. Whilst the initiation of the sexual phase represents a climax in the life of all flowering plants, in cases such as the banana, which is a comparatively short lived plant grown for its fruit, the significance of this climax is accentuated from the point of view of agriculture.

As has been recorded earlier, no leaves are extruded by the banana plant subsequent to the appearance of the inflorescence. Both the leaves and the floral parts arise in the same apical region (Plates 11-19) and once the sexual phase is initiated no further foliage leaves are laid down, the whole of the meristematic activity being then devoted to the production of flowers or organs, such as bracts, directly associated with them. Nevertheless, any immature leaves which are present in the pseudostem when flower bud initiation commences are developed to maturity, extruded in the normal manner, and precede the inflorescence to the throat of the plant. Thus until the last leaf unfurls there is no outside manifestation of the beginning of the fruiting phase which has taken place within the plant. It is obvious that if the development of the plant is to be followed and understood it is necessary to have earlier knowledge of the vital change than can be obtained by external examination.

There are probably few botanical phenomena which have attracted more attention than the conditions which attend the initiation of the sexual stage. Whilst considerable progress has been made in some directions, notably phasic development of plants and certain chemical aspects, there are still many wide gaps in our knowledge which must be filled before practical use can be made of much of the information. So far as the banana is concerned, all that was known was that the banana may flower at any season of the year, including the middle of winter and the middle of summer, and that the plant produces but one climax inflorescence. The latter point suggests that increase in size is not unconnected with flowering.

Using the data obtained from the growth study and field trial plants the following postulates were accepted as a basis in the search for a point common to all plants at an appropriate time:—

1. All plants which flowered must have been subject to the same causal condition.
2. The plant must respond to this condition and in the event of the same set of conditions occurring more than once in the life of the plant the response must have taken place during the first occurrence.

3. There must be no such response in the absence of these conditions.
4. In view of the large number of dissections showing that in well-developed plants the number of immature leaves at any one time was approximately 11 and never less than eight, the date of the response should be approximately such that 11 leaves were extruded by the plant between the computed date of flower initiation and the appearance of the inflorescence. It will be remembered that the number of immature leaves found in dissected plants was smallest in the youngest plants, and therefore some variation may be allowed in conformity with this evidence.

The underlying reasons for each of the first three points are obvious, but the choice of number of leaves may be a little more difficult to follow since the number suggested is that for leaves which were large enough to be dissected out with a needle; but there are still two or three less differentiated initials, which can be seen under low magnification, behind those accounted for. It will be noted from the general description of the structure of the plant that, in addition to the bracts which subtend the hands of flowers, there are always at least two larger ones which protect the whole inflorescence. These bracts are, of course, modified foliage leaves. Even the last foliage leaf is somewhat different in shape from the preceding ones, the former being generally shorter and broader. This "spade" leaf, as it is called, frequently has the lamina so greatly reduced that its area is negligible. The smaller, less differentiated, buds are thus to be accounted for as bracts subtending the inflorescence and the basal hands of flowers and are not included in the total to be matured as foliage leaves.

As has been recorded above, there was no evidence that temporary accumulation or reduction in the number of developing leaves occurred and it was concluded that leaf bud initiation took place at much the same rate as leaf extrusion. From this it follows that in plants of an advanced age the date of initiation of a particular leaf is close to the date of unfurling of the leaf 11 in advance of it. The number would, of course, vary somewhat in accordance with the age of the plant, as has already been described. As a consequence of this, then, it follows that the conditions at the time of appreciable differentiation of the last leaf and the initiation of the first flower bud are in most plants approximately those pertaining at the time of extrusion of the 11th last leaf. It seems possible that the degree of modification of the spade leaf might be taken as an indication of the degree of development it had undergone before flower buds were commenced, just as the major bracts of the inflorescence are less modified than the smaller ones which subtend the hands.

The second and third points can be checked positively in the case of the growth study plants but with the field trial plants the evidence must be largely circumstantial.

The early conception of the production of sex organs was that this took place as a direct consequence of growth and followed automatically as the result of nutrition. The original theory thus meant that internal factors alone controlled the development of the plant in this respect. Klebs, as reported by Stiles

Plate 11.

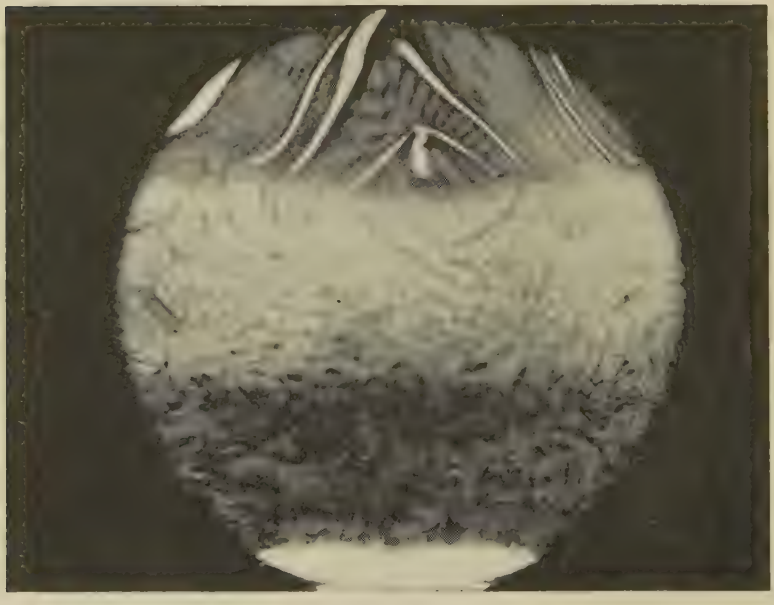


Plate 12.

(1936, p. 394), showed experimentally that external factors could also be of moment and more recent work on the phasic development of plants in connexion with such problems as vernalization emphasises that the growth of a plant and its development are by no means identical. It was not expected, therefore, that any of the simple data which had been collected would yield much information, but nevertheless in the first analysis each of the sets of these data was examined. Thus the total area which had been produced, the rate at which unit leaf area was being unfurled, the actual area produced at any one time, and the day-square inches of the plants, were each given consideration. Whilst there was, as might be expected, a tendency for like plants to group themselves in respect to some of these measures there was no evidence from any of these statistics of a point common to all or even to the majority of the plants.

Consideration of Light.

Garner and Allard (1920, 1923) in a series of very important investigations first showed the dominant role played by length of day and illumination in the production of flowers by a large number of plants, and though the banana is not apparently subject to photoperiodic control it is of importance to examine the influence of light in relation to the initiation of its sexual phase.

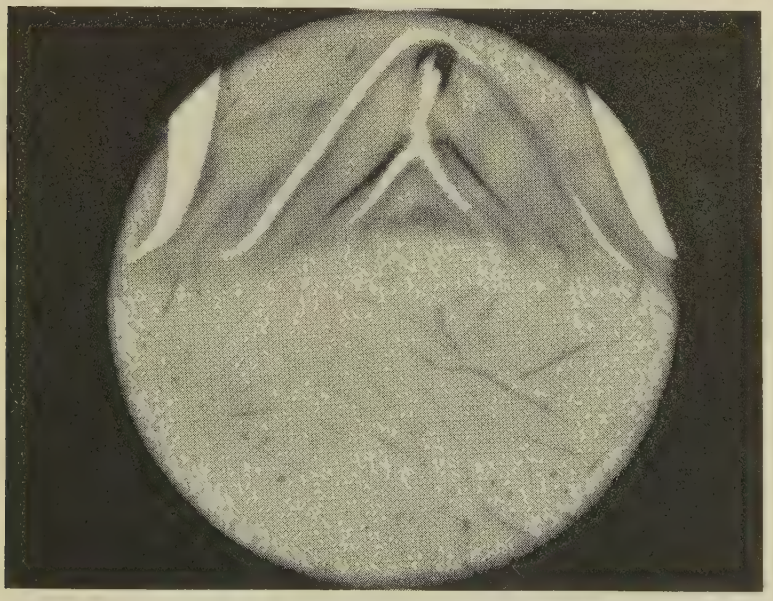


Plate 13.

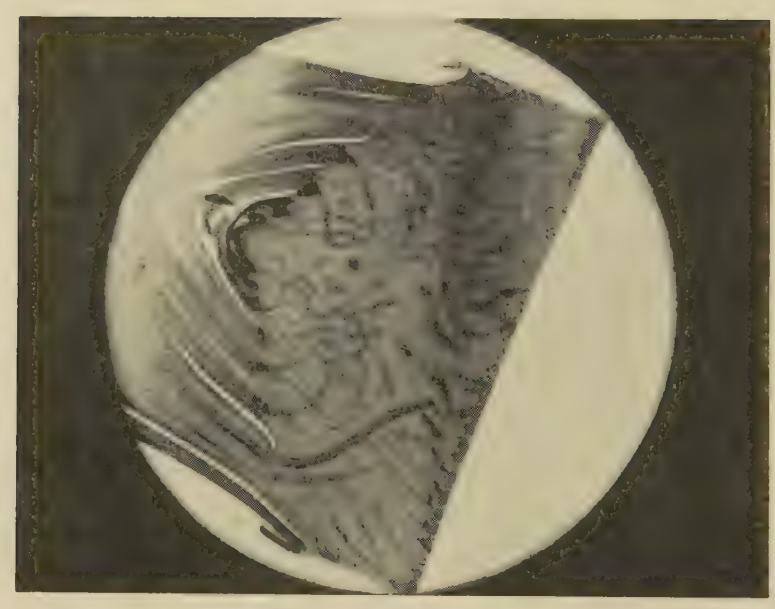


Plate 15.

Plate 14.

As has been indicated, banana flowers may be found on every day of the year; and therefore it seems that, unless there are considerable differences between individuals in the period between bud differentiation and the extrusion of the inflorescence, the effect of illumination, if this is a determining influence, must be connected with a total amount, or an increased rate, of absorption of energy at a particular time. That is to say differences, not being attributable to the length of day itself, must depend on the potentiality of the plant for its utilization; and obviously this potentiality must tend upwards to a limiting point, since the plant gets nearer to flowering as it increases in size. There is a great

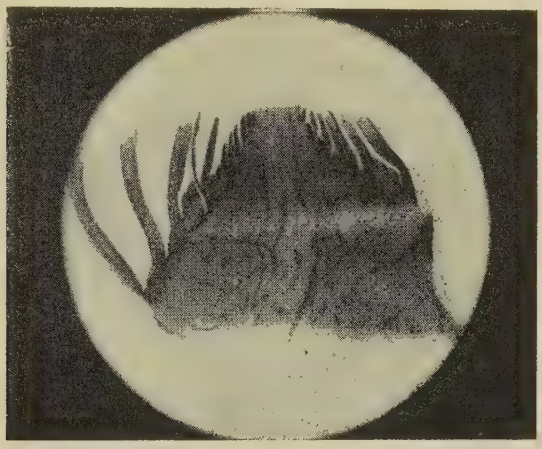


Plate 16.

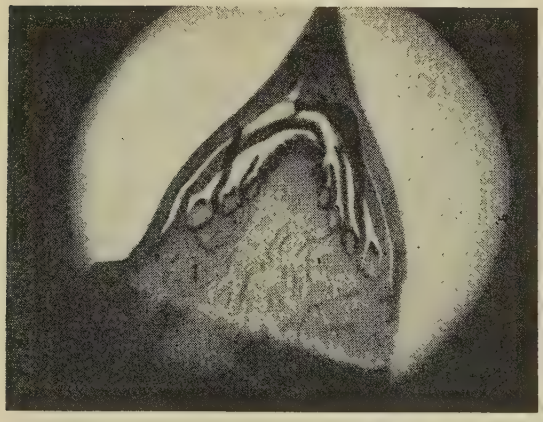


Plate 17.

deal of evidence to show that the period of development from bud to flower extrusion does not vary greatly between plants at any one season of the year. The data, then, may be examined on this basis.

Relation of Area of Leaf on the Plant to Bud Initiation.—The potentiality of the plant to absorb energy from the sun at any particular time may, at this stage, be taken as proportional to the area of leaf on the plant. In interpreting the data from the growth study plants there is the difficulty that, in the absence of a very large series, it is impossible to say how far from budding an unbudded plant is or how old the bud is when found. The data obtained can only set the limits, and for the purpose of investigation at this stage an arbitrary figure was chosen within those limits. After a series of trials made from the data from all available plants, an area equivalent to 10,640 square inches in June was found to give the most satisfactory results, except that plant

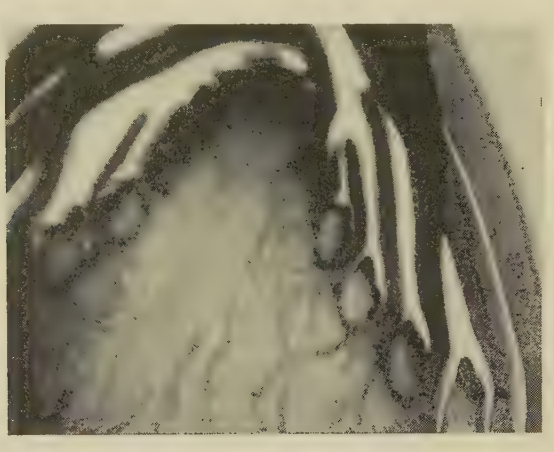


Plate 18.

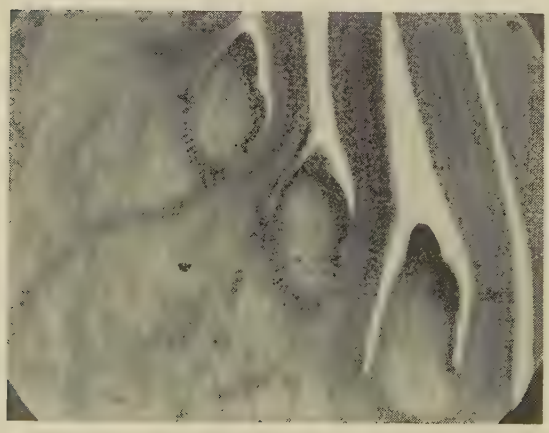


Plate 19.

EXPLANATION OF PLATES 11-19.

FLOWER BUD INITIATION.

Plate 11.—Section through apex of corm before flower bud initiation. Note that the top of the corm forms a slightly concave line.

Plate 12.—Section through apex of corm, similar to Plate 11.

Plate 13.—Section through apex of corm, showing the change from a concavity to a convexity. This is the first indication of flower bud initiation and is caused by the corm commencing to form its aerial stalk. The section is from Plant 21A, for which Ts x Area Produced = 56,000 x 10^7.

Plate 14.—Section through apex of corm, with the flowering bud slightly more advanced than that in Plate 13. Note that the elongation of the apex is more pronounced.

Plate 15.—Section through apex of corm, showing the youngest actual flower buds obtained. These can be seen as dark structures in the axils of the bracts. For this plant Ts x Area Produced = 63,000 x 10^7.

Plate 16.—Section through apex of corm and flower stalk, showing flower buds in a more advanced stage. Note the dark area at the base showing the straight line of the corm surmounted by the flower stalk.

Plate 17.—A similar section to that in Plate 16.

Plate 18.—Section showing later stage in bud initiation. Note the vascular strands supplying both bracts and flowers, whereas previously the strands ran only to the leaves. For this plant Ts x Area Produced = 83,000 x 10^7.

Plate 19.—Portion of the same section as in Plate 18.
All photomicrographs are of hand sections stained with haematoxylin.

Magnification.—Plates 11-15, x 12·5; Plates 16-17, x 6; Plate 18, x approx. 37; Plate 19, x approx. 80.

EXPLANATION OF PLATES 20-23.

DEVELOPMENT OF FLORAL ORGANS.

Plate 20.—Inflorescence just emerged from throat of pseudostem. Note the modified "spade" leaf and the enclosing bracts.

Plate 21.—The bracts lifting in acropetal succession. The basal hand of flowers can be seen to be well advanced, the ovary being more than four inches in length.

Plate 22.—Further hands exposed.

Plate 23.—Basal "female" hands exposed and the subtending bracts are shed. The "hermaphrodite" flowers are also opened. The "male" flowers are still tightly enclosed under the bell of bracts at the distal end.

A4 of the growth study series had attained this area many weeks before dissection but showed no sign of flower bud when examined. The standard was persisted with, however, since the variation between plants was unknown; and though no error could be detected the possibility could not be ignored. On the basis of number of hours of sunlight the monthly equivalents of area are as follows:—

	Sq. inches.		Sq. inches.
April	9,600	September	9,200
May	10,100	October	8,600
June	10,640	November	8,100
July	10,400	December	7,790
August	9,900	January	8,050

Table 13.

FLOWER BUDDING DATE AS CALCULATED FROM LEAF AREA.

Plant No.	Budding Date.	Flowering Date.	No. of Leaves Matured Subsequently.	Plant No.	Budding Date.	Flowering Date.	No. of Leaves Matured Subsequently.
20A ..	Apr. 20	Oct. 24	10	8A ..	Sept. 12	Jan. 11	10
19A ..	Apr. 21	Oct. 24	10	24A ..	Oct. 7	Jan. 15	10
19B ..	May 10	Nov. 7	10	8B ..	Oct. 9	Jan. 15	9
24B ..	May 11	Oct. 31	10	15A ..	Oct. 9	Jan. 13	10
21B ..	May 12	Nov. 9	11	17A ..	Oct. 17	Jan. 11	8
14A ..	May 12	Oct. 24	9	6B ..	Oct. 17	Jan. 9	8
18A ..	May 17	Nov. 7	10	13A ..	Oct. 21	Jan. 30	10
25B ..	May 18	Nov. 14	11	30A ..	Oct. 27	Jan. 3	7
10B ..	May 24	Oct. 31	9	29A ..	Oct. 29	Jan. 28	9
3B ..	May 26	Oct. 31	9	16A ..	Oct. 29	Jan. 30	10
18B ..	May 19	Nov. 7	10	27B ..	Nov. 6	Jan. 2	6
17B ..	May 25	Nov. 10	10	9A ..	Nov. 6	Jan. 19	10
4B ..	May 26	Nov. 7	10	27A ..	Nov. 7	Jan. 19	10
29B ..	June 1	Nov. 21	11	9B ..	Nov. 6	Jan. 20	9
11B ..	June 2	Nov. 16	10	30B ..	Nov. 14	Jan. 20	7
11A ..	June 15	Nov. 13	10	31A ..	Nov. 15	Jan. 20	7
23B ..	July 2	Nov. 21	9	16B ..	Nov. 15	Jan. 30	8
7A ..	July 2	Nov. 28	9	26A ..	Nov. 16	Jan. 25	10
3A ..	June 16	Nov. 29	11	13B ..	Nov. 17	Jan. 17	10
2B ..	July 11	Dec. 5	11	32B ..	Nov. 9	Jan. 17	9
15B ..	Aug. 6	Nov. 28	8	5A ..	Nov. 22	Jan. 14	6
14B ..	Aug. 6	Nov. 28	8	7B ..	Nov. 22	Jan. 20	7
22A ..	Aug. 8	Nov. 21	7	1A ..	Nov. 26	Jan. 16	6
22B ..	Aug. 15	Dec. 5	8	6A ..	Nov. 26	Jan. 20	8
4A ..	Aug. 22	Dec. 23	11	2A ..	Nov. 13	Jan. 30	9
25A ..	Sept. 4	Jan. 9	11	12B ..	Nov. 29	Jan. 30	9
23A ..	Sept. 12	Dec. 16	8	5B ..	Dec. 6	Jan. 30	7
20B ..	Sept. 23	Nov. 14	4	32A ..	Dec. 9	Feb. 27	9
26B ..	Sept. 11	Dec. 23	9	1B ..	Dec. 18	Feb. 20	8
10A ..	Sept. 30	Jan. 9	10	21A ..	Dec. 26	Mar. 5	8
12A ..	Sept. 2	Nov. 7	4	28B ..	Dec. 31	Mar. 20	9
28A ..	Oct. 6	Jan. 2	8	31B ..	Jan. 8	Mar. 5	6

This set of standards was then applied to the field trial plants and the earliest date on which each reached the required area was taken tentatively as the date at which budding occurred. The results obtained are set out in Table 13.

Though the results show a general serial trend there are many variations and inconsistencies which must be explained before any acceptable theory can be based on the premises involved. For the most part the number of leaves which were extruded after the plants reached the required standard of area was somewhat at variance with the information obtained in the dissection work. In general the number of such leaves is lower than would be expected and in several cases is so far below the expected figure that the whole series is left open to much doubt. Further, the trend is in the opposite direction to that shown by the dissection work, in that plants flowering early developed more leaves than those which were older at flowering time.

It may be noted that the plants in plots receiving nitrogen only as a dressing produced an appreciably lower average number of leaves after reaching this potential than did the plants in any other plot, the averages being—K 9·6, PK 9·5, NP 9·5, NK 9·4, NPK 8·7, P 8·5, and N 6·9. Even though this point may not have a bearing on budding time there remains the fact that the leaf areas were equivalent in apparent potential for light absorption and thus the nitrogen-treated plants reached this position later in life than the others. This may be taken as meaning that the development of plants which received nitrogen only was further advanced than that of plants treated otherwise and with which it might be expected comparisons could be made. It is to be noted that potentiality for light absorption only has been taken into account. That leaves with higher nitrogen status may have increased power of assimilation would need consideration in an exhaustive study.

The position found may be summarized by saying that the apparent relationship between the area of leaf on the plant, as qualified by the duration of sunlight, and the development of the flower bud is at least no stronger than would be expected between any two sets of figures reflecting activities which it is certain cannot be wholly independent.

Other Barren Approaches.—Following these results a number of other tests were made, but in no case was any better result achieved. In most cases a botanical interpretation of the applied formulae could be readily found, but in others the formulae were tested though the botanical meanings, if existent, were obscure. In this barren work the following formulae were tested:—

$$A_0 \times D \times T;\ A_0 \times T;\ \frac{A_0 \times D \times T}{Ap};\ \frac{A_0 \times D \times T}{P};\ A_0 \times D \times T \times P;\ A_0 \times D \times Ap;$$

$$\frac{A_0 \times D \times Ap}{P};\ \frac{A_0 \times D \times T \times P}{Ap};$$ and each of these in proportion to the total area of leaf produced up to the appropriate time; where A_0 = the area of leaf on the plant, D = the number of hours daylight, T = the mean temperature in degrees Fahrenheit, Ap = the area of last leaf produced, and P = the period required for the extrusion of the last leaf. All measurements are, of course, referred to

the date for which the test was being made. In the course of this portion of the work many tests were applied using temperatures above a fixed point. Thus the number of degrees above 20°, 30°, and 40° was used in three separate series.

Differential Coefficient of Leaf Values.—Although so many formulae based primarily on the area of leaf exposed at a time approximating to what was held to be the appropriate date for budding thus failed to give any sign of a suitable budding point common to all plants, this factor cannot be dismissed without further investigation. As has been mentioned earlier, there remains the possibility that leaf area should be corrected for age by the application of a differential coefficient. It cannot be assumed that a leaf say seven days old,

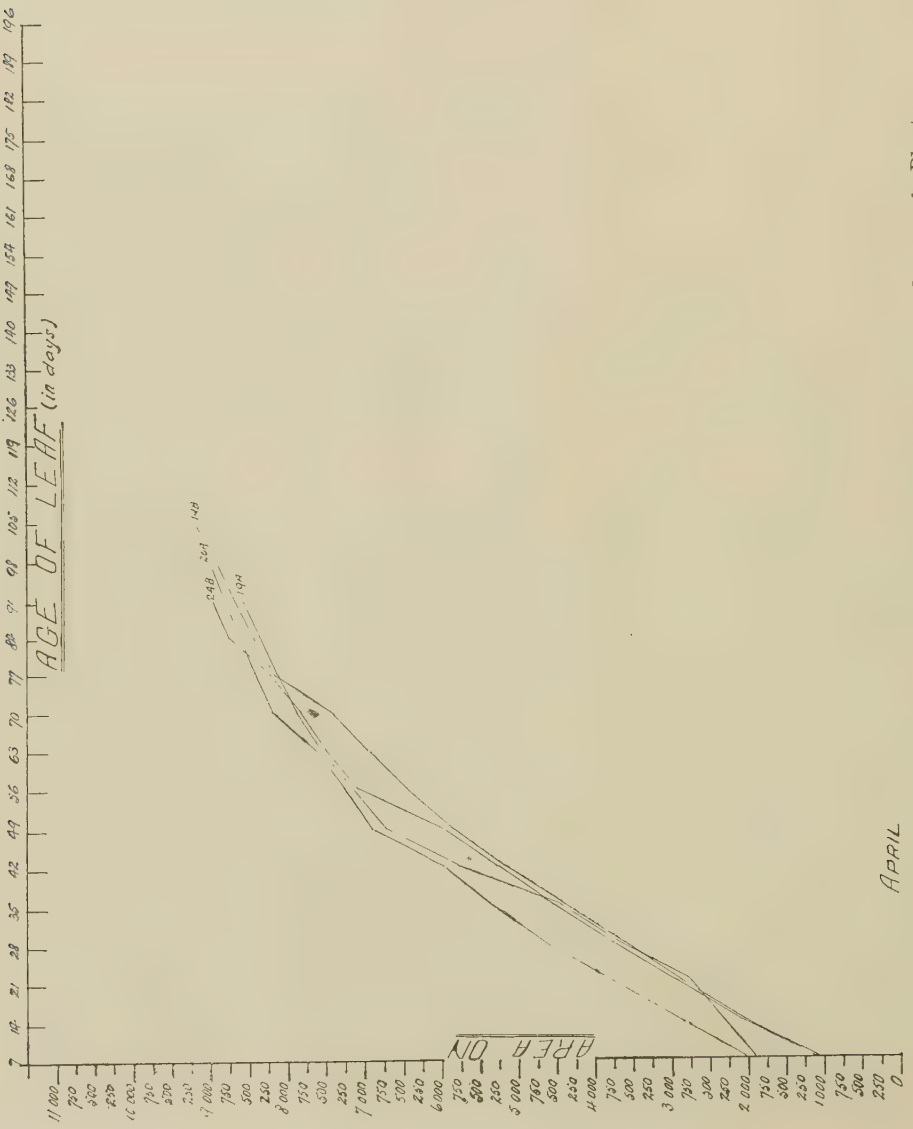


FIG. 13.—Showing Total Area of Leaf less than the age indicated on each Plant which Produced its 12th last Leaf in April.

one that has been unfurled for 70 days, and another twice that age, all function with the same efficiency with respect to any phase of activity. Accordingly, though the difference due to varying efficiencies correlated with age did not, from general inspection of the figures, appear to be likely to offer a solution, it was necessary to examine the data in some detail. To do this graphs were drawn from the data for each of the 64 plants in the field trial. As it could be assumed that the point being searched for occurred in the vicinity of time

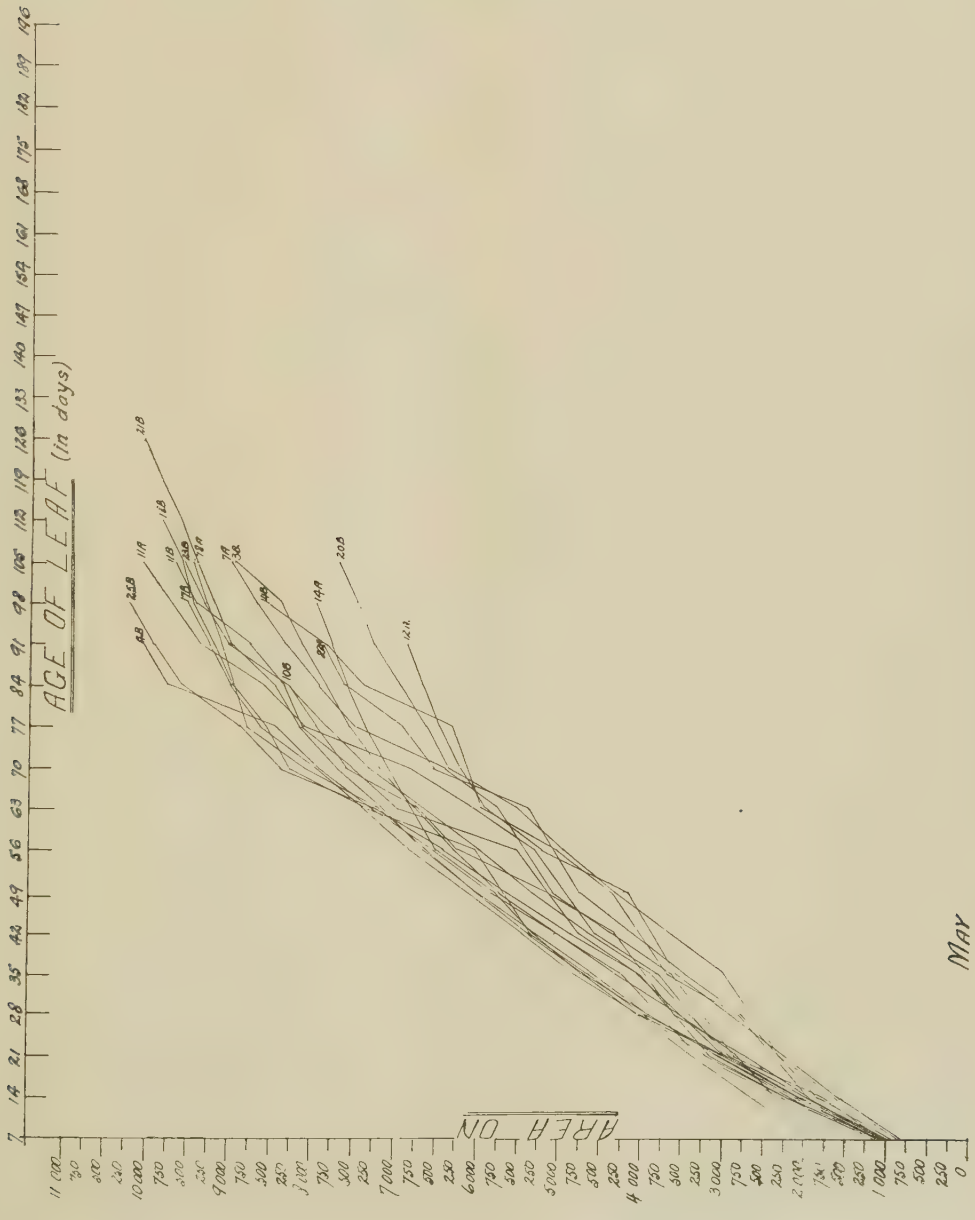


FIG. 14.—Showing Total Area of Leaf less than the age indicated on each Plant which Produced its 12th last Leaf in May.

of unfurling of the 10th to 12th last leaf for the majority of plants the area of leaf on the plants at those times was plotted so as to show the amount of the leaf surface which was of any particular age. The area on the plant does not as a rule fluctuate at all violently and it was concluded, therefore, that any error caused by taking a leaf one or two removed from the correct one would not obscure any facts in the general body of the information if any degree of reliance could be placed on the evidence of dissection.

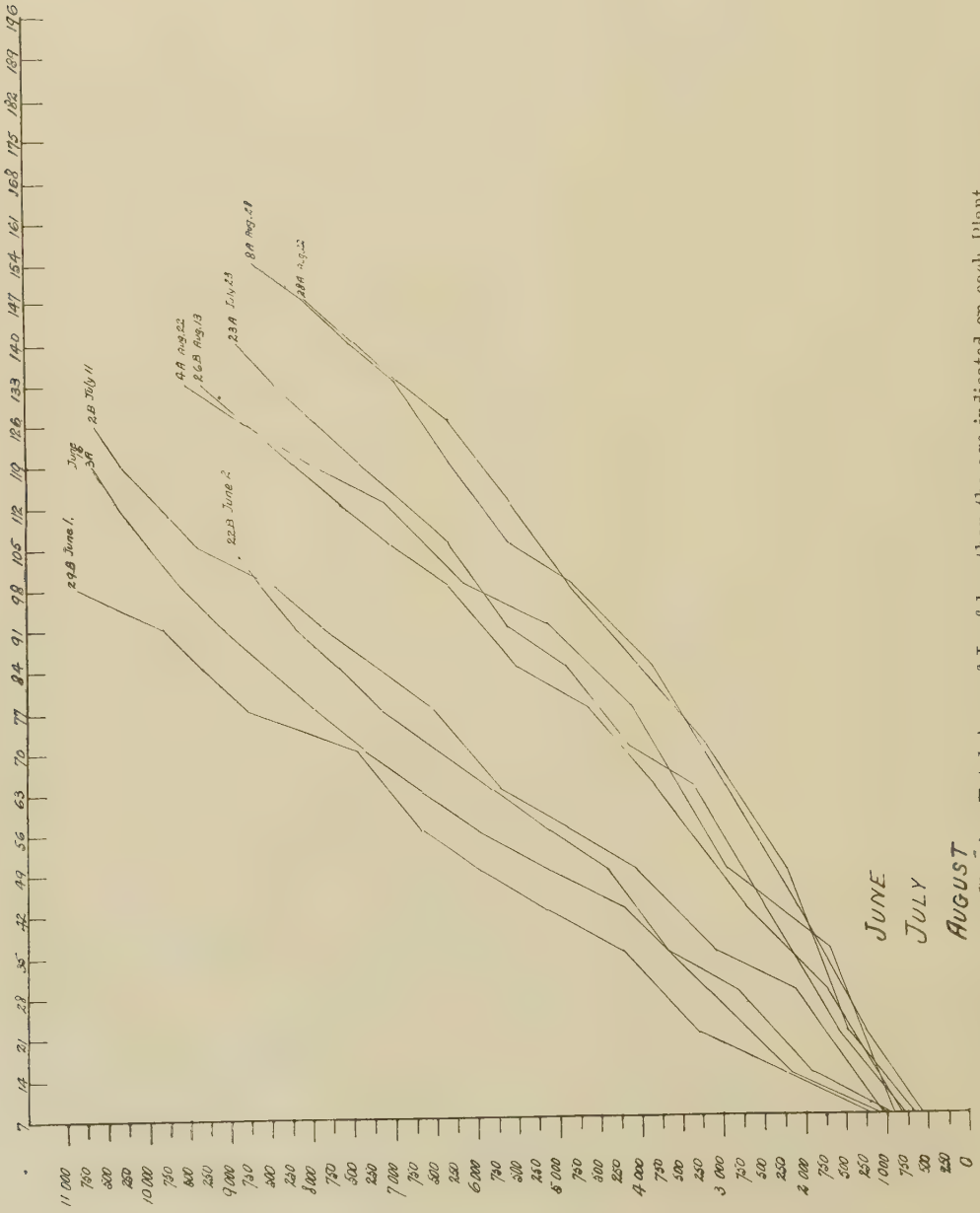


FIG. 15.—Showing Total Area of Leaf less than the age indicated on each Plant which Produced its 12th last Leaf in June, July, or August.

Figures 13-17 show the position at the time of unfurling of the 12th last leaf, whilst that at the 10th last leaf is shown for certain plants in Figure 18. It is patent that plants which simultaneously produce leaves comparable with respect to flowering time tend to have similar areas; but at the same time within these general groupings there are wide variations which are not offset by any conceivable coefficient dependent on the age, even allowing that the variation may not always be in the same direction. For example, comparison may be made between

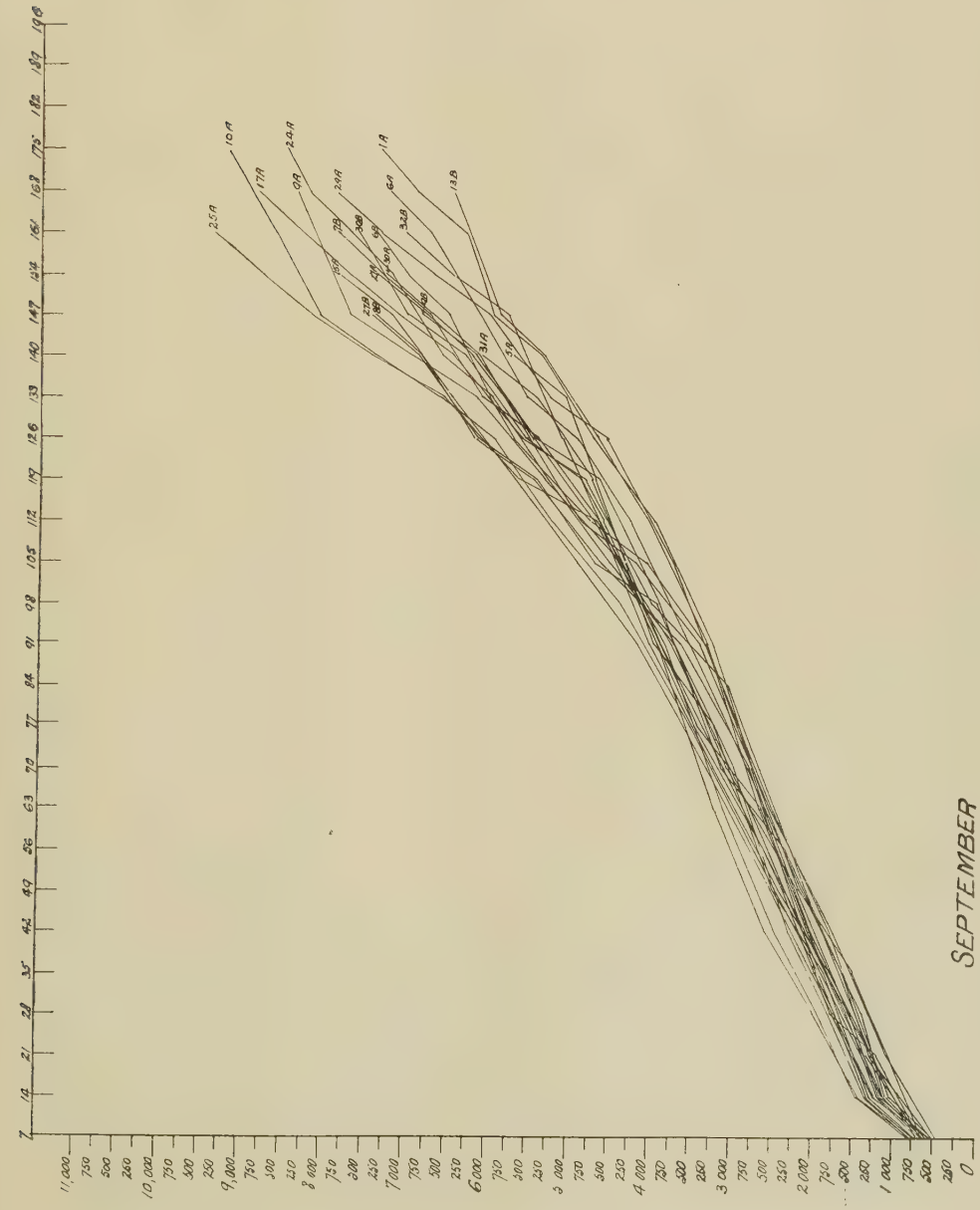


FIG. 16.—Showing Total Area of Leaf less than the age indicated on each Plant which Produced its 12th last Leaf in September.

plants 5A and 10A, which received the same manurial treatment and which flowered but five days apart. The total area on plant 5A when the 12th last leaf had completed development was 5,750 square inches, at which stage 10A displayed more than 9,000 square inches. At the corresponding time for the 10th last leaf, the respective areas were 6,500 and 10,000 square inches. It is difficult to follow the graphs for the whole of any particular plant, but the figures from which they were drawn show that 5A had a smaller area at every

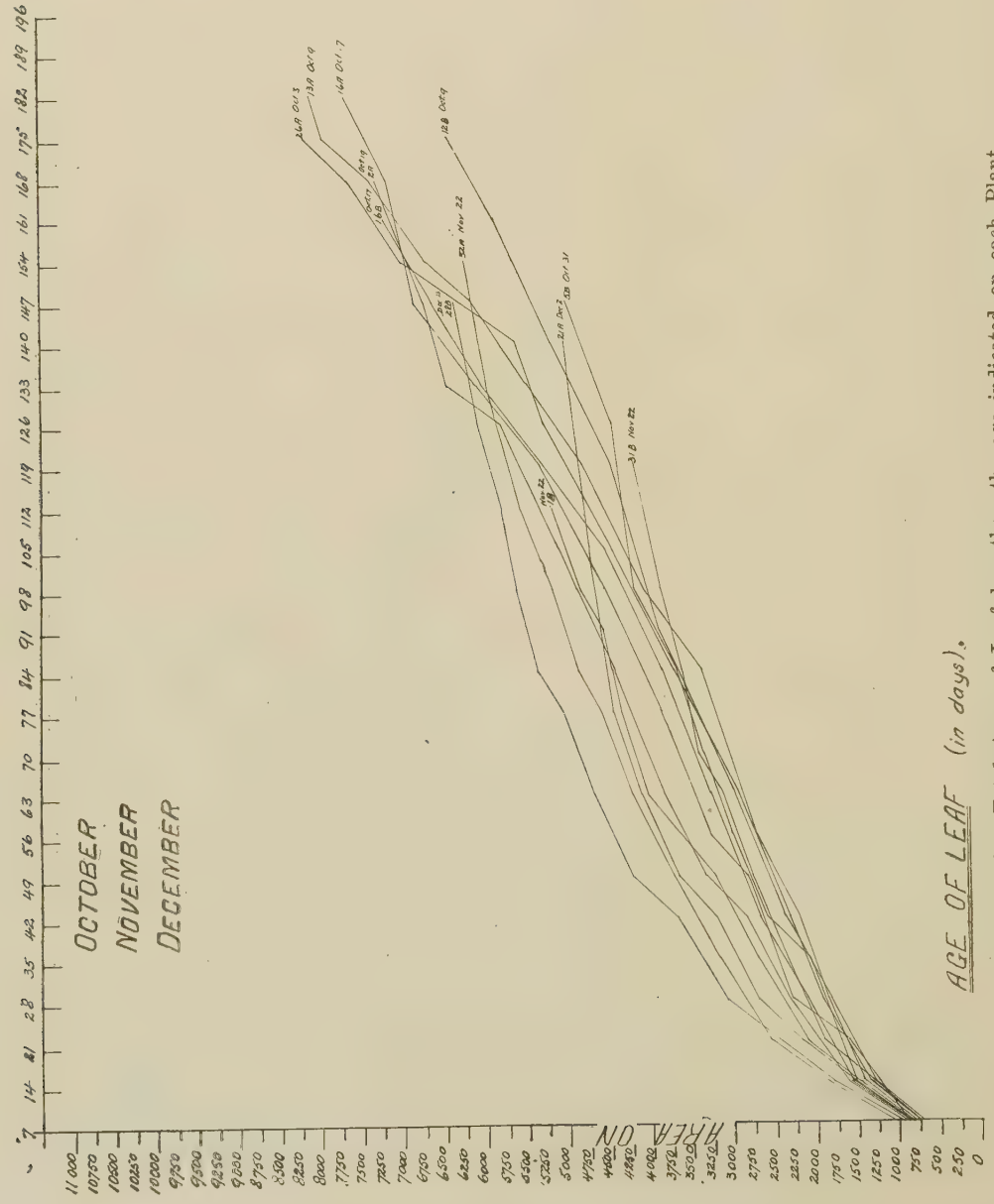


FIG. 17.—Showing Total Area of Leaf less than the age indicated on each Plant which Produced its 12th last Leaf in October, November, or December.

stage except in respect to leaves less than 14 days old at the date of extrusion of the 12th last leaf. At this point 5A had less than 20 square inches more than 10A. Again, in the May chart it will be noted that plants 20B and 12A remain low throughout and have total areas more than 3,000 square inches below that of several apparently comparable plants. In general there is an absence of that spindle formation which would be expected if a differential coefficient were operating.

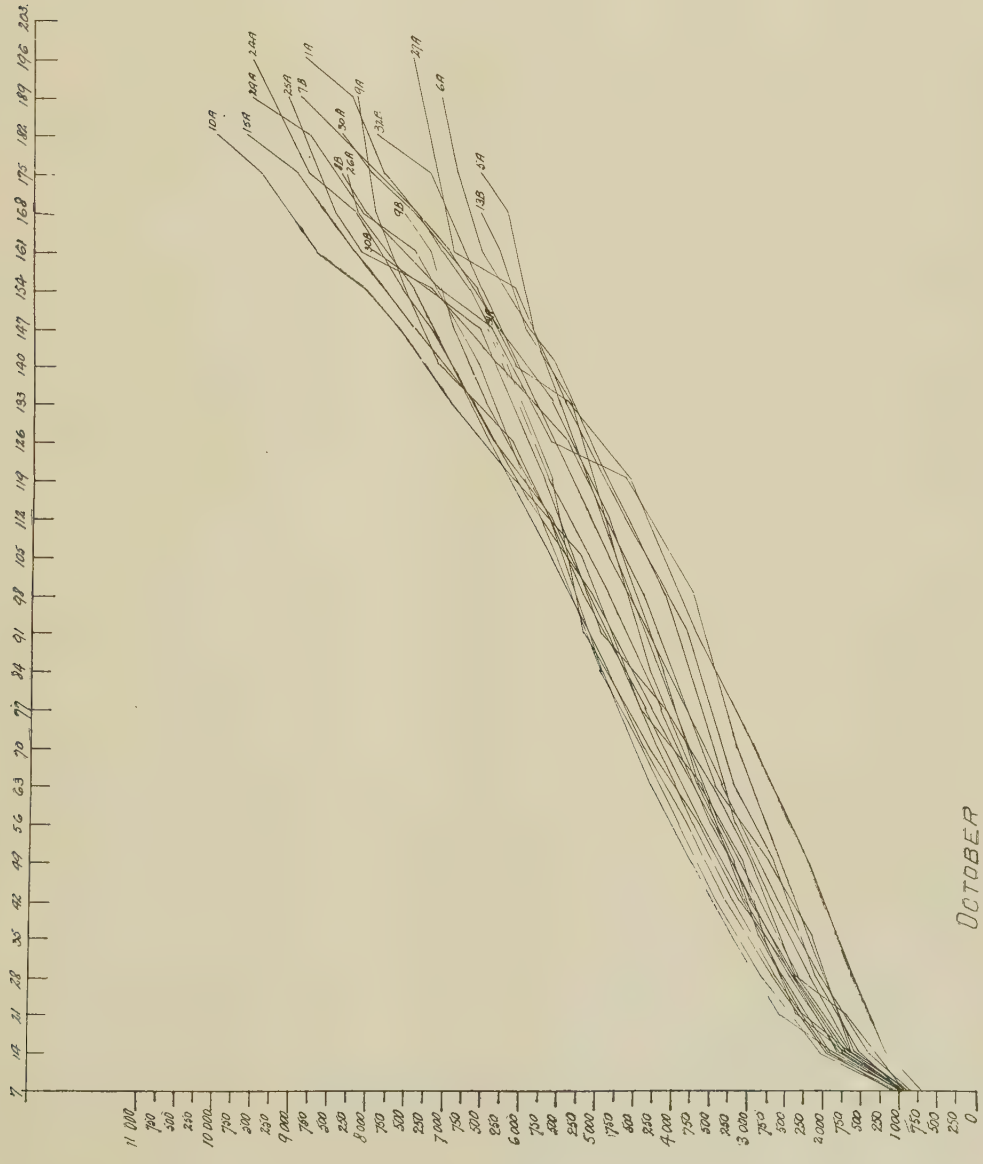


FIG. 18.—Showing Total Area of Leaf less than the age indicated on each Plant which Produced its 10th last Leaf in October.

The Significance of Rate of Leaf Area Production.

The one fact which can be observed as reasonably consistent in Figures 13-18 is that the area of the last leaf produced tends towards the same point within each monthly grouping. The variation is, however, still quite large and an examination of the plant records does not suggest that mere ability to produce a leaf of more than a certain area is closely correlated with the subsequent production of 10 to 12 more leaves.

It appears then that, if the initiation of the sexual phase is in fact correlated with foliage production or foliage potentiality, the relationship is not a simple one but has two or more components. Combinations of possibly contributing factors were therefore examined and Figures 19 and 20 show the principal data for two plants chosen for similarity in bunching times and treatment but for variation in the area of leaf exposed at about the presumed critical period. Figures 21 and 22 are included to show certain of the data for plants which were dissimilar in many respects.* The rate of production of leaf area used was not a true figure since the whole of the leaf was not developed over the time used and, further, other leaves were being developed concurrently. In tracing the development of the leaf there are several difficulties. In the first place, the final area which an immature leaf will attain cannot be determined. Further, the immature leaf tissues are extremely brittle and fragile and if they are artificially hardened it is almost impossible to unroll the tightly packed lamina in one piece for the purpose of measuring the linear dimensions. Weight comparisons between immature and mature leaves are not valid, as even the most cursory examination will show.

Examinations were made on a number of occasions when it could be assumed that the next leaf to be extruded would at least equal in area that of the latest unfurled one. It was found that at these times the leaf in Stage 1 had reached practically its full width but had still to elongate appreciably. The next leaf following was found never to have attained more than half its probable ultimate width and generally much less than half its length of mid-rib. On a weight basis it was commonly found that the most advanced of the immature leaves, excepting that partly extruded, was approximately equal to the aggregate of all those less advanced than it. It is clear that the greatest absolute increase in mass takes place late in the development of the leaf and thus the rate used can be accepted as a measure of the daily production of leaf tissue at the time chosen.

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* The legend for Figures 19-22 is as follows:—

R is the rate calculated by dividing the area of the last leaf unfurled by the number of days elapsing since the previous leaf reached the same stage;

TA is the total area produced up to the time;

AO is the area remaining on the plant; and

AP is the area of the last leaf unfurled, all points being referred to the appropriate date in each case.

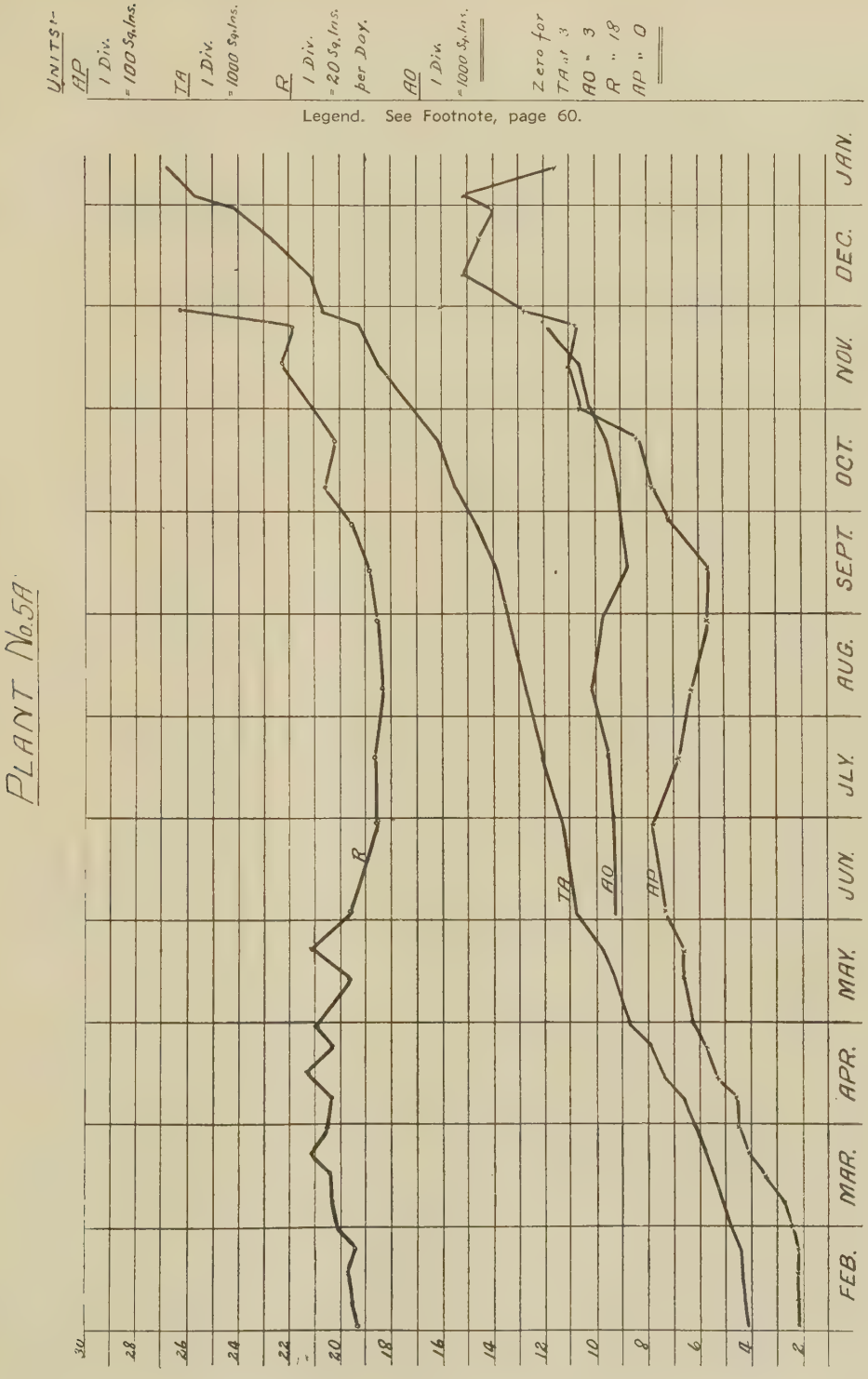
PLANT No. 5A
UNITS—
AP
1 Div. = 100 Sq. Ins.
TA
1 Div. = 1000 Sq. Ins.
R
1 Div. = 20 Sq. Ins. per Day.
AO
1 Div. = 1000 Sq. Ins.
Zero for
TA at 3
AO " 3
R " 18
AP " 0
Legend. See Footnote, page 60.
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
FEB.
MAR.
APR.
MAY.
JUN.
JLY.
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
R
TA
AO
AP

Fig. 19.

PLANT No. 10A
UNITS:-
AP
1 Div. = 100 Sq.ins.
TA
1 Div
= 1000 Sq.ins.
R
1 Div.
= 20 Sq.ins.
per day
AO
1 Div.
= 1000 Sq.ins.
Zero for
TA at 3
AO = 3
R = 18
AP = 0
Legend. See Footnote, page 60.
JAN.
DEC.
NOV.
OCT.
SEPT.
AUG.
JLY.
JUN.
MAY
APR.
MAR.
FEB.
30
28
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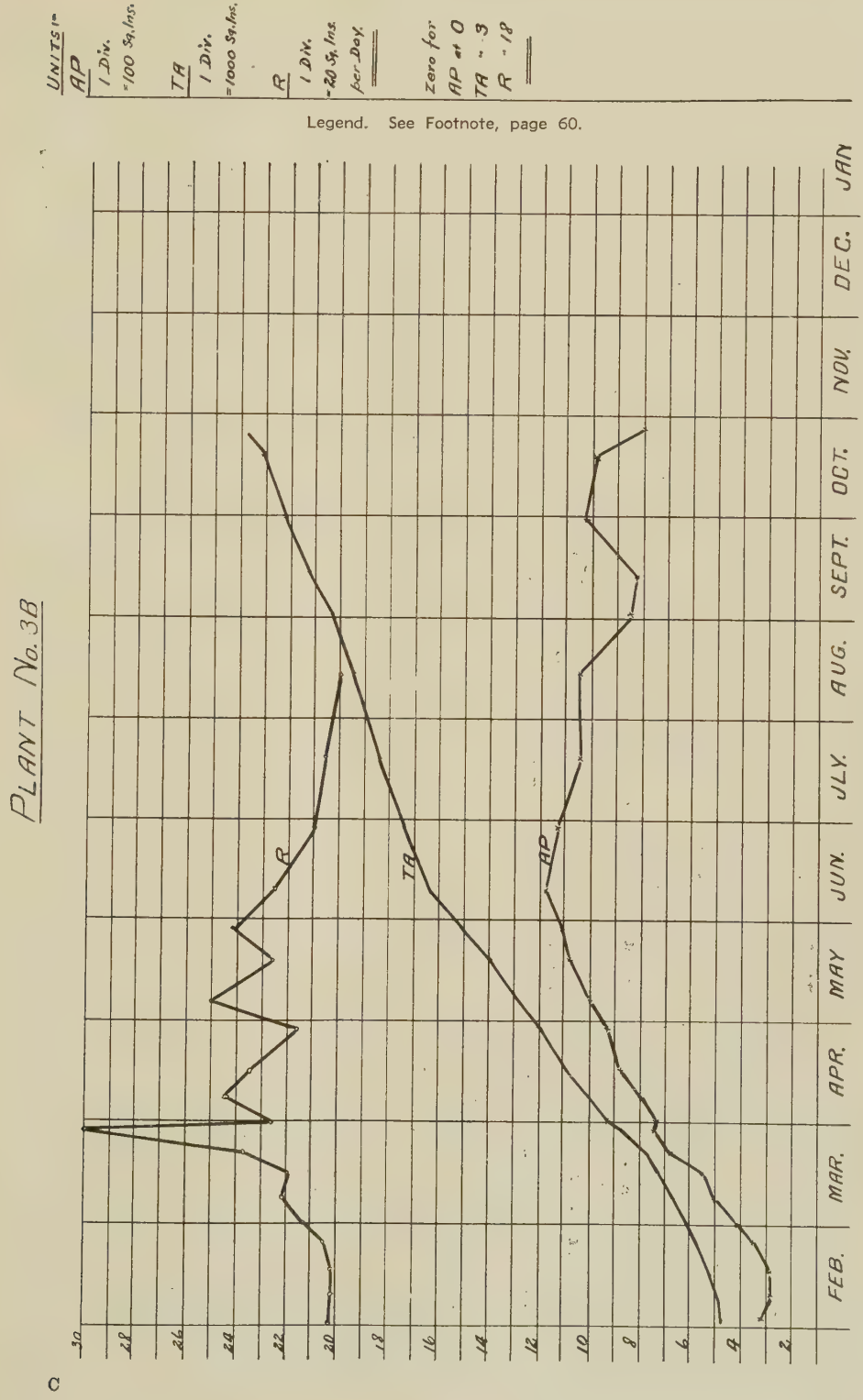
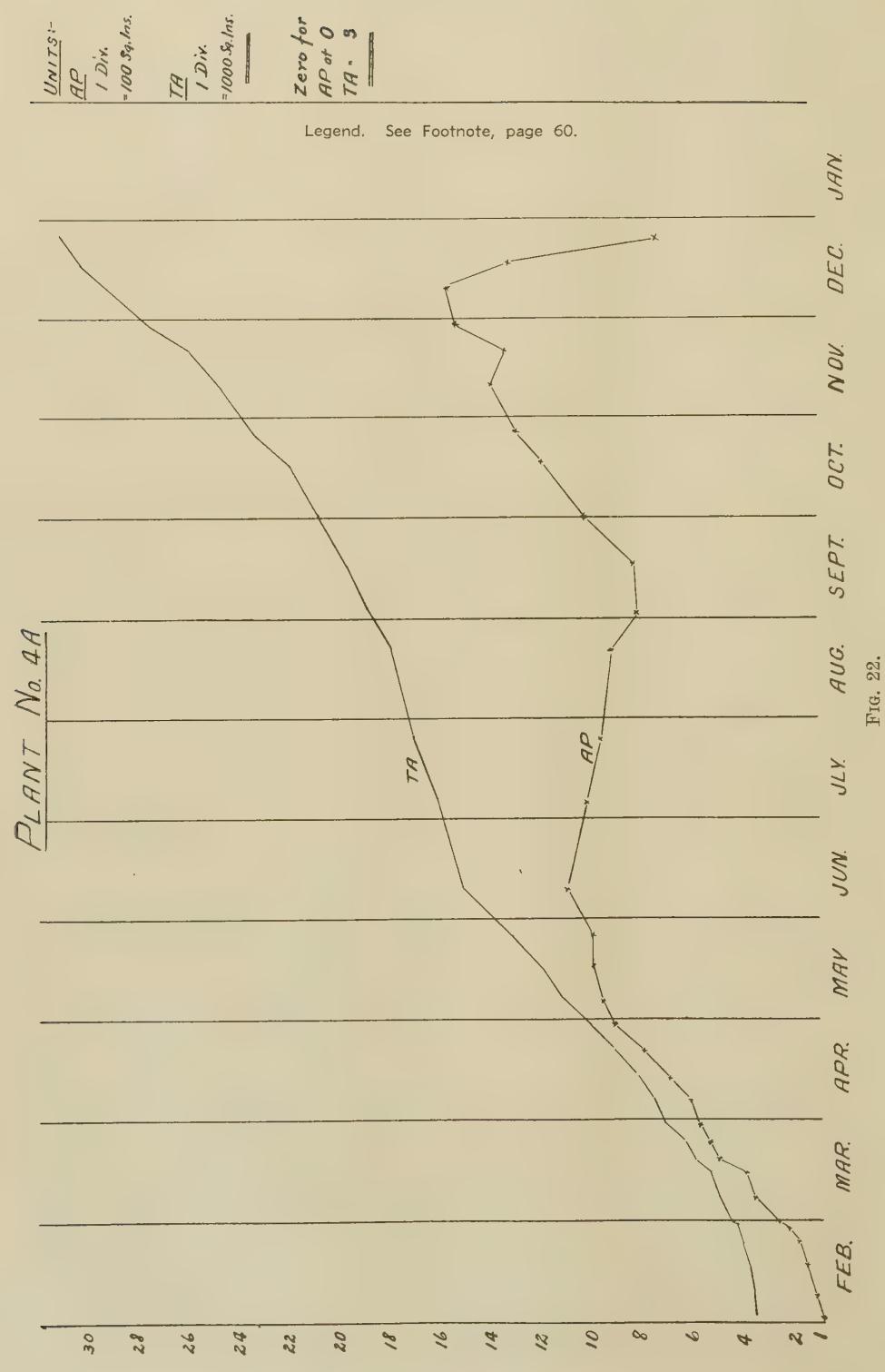
R
TA
AO
AP

FIG. 20.



Legend. See Footnote, page 60.

FIG. 21.



Legend. See Footnote, page 60.

FIG. 22.

Reverting to Figures 19 and 20, it will be seen that variation in functional areas between two plants is not compensated by fluctuations in any other measured factor and therefore its place as a part of any combination is very doubtful. Total leaf areas, of course, increase practically continuously, and the area produced at any one time and the rate at which it is produced naturally reflect each other to some extent. The 12th last leaf in each case is found in September and at this time both rate and area produced are rising and both plants give closely similar figures in respect to each of their measurements. These are, therefore, worthy of further examination. As has been recorded earlier, neither is of value considered by itself. The diagrams show that neither is at the maximum it has so far attained; and the minimum of each would, of course, occur very early in the life of the plant. The next step then was to study the relation between the total areas and the figures of rate and production.

From simple considerations the rate would appear to be the more promising factor and in the first place this was used. However, although a satisfactory date was given for the bud initiation of most of the plants, a few yielded less satisfactory results, whilst in a small number no possible date was obtainable.

It then became necessary to investigate the area of the particular leaf instead of the rate at which it was elaborated, and when this was combined with total area as a multiple a fairly satisfactory series of points was obtained. However, if a standard were set up for a particular time, though all the plants which obviously budded about that time fitted the scheme very well, higher or lower values had to be used for the others according to whether they budded before or after the time chosen for allotting the standard, and obviously some factor connected with time was operating.

Further Consideration of Light in Conjunction with Temperature.

While the total leaf area produced by a plant may be expected to reflect to a degree the amount of growth, as has been shown earlier there is not a simple proportion between the two and other factors must be given consideration. So far as reproduction is concerned the results of many workers have drawn attention particularly to the effects of light and temperature and it seemed logical, therefore, to examine the position with respect to these two factors in relation to the area of leaf produced. Total leaf area as a factor failed to yield the exact information sought relative to budding date but there was some indication of a connexion between the two. In view of the fact that it was total leaf which seemed to be implicated and that photoperiodism did not enter into the question, it was a total or an accumulated effect which was looked for rather than a specific rate.

The first question to be decided was what measures of light and temperature could be employed. With respect to light both intensity and duration might be of moment. Intensity is of particular importance in connexion with photosynthesis but in so far as reproduction is concerned research

has emphasized the importance of duration. With respect to intensity, too, it is difficult to visualize how a measure could be obtained, since position of leaf on the plant would be such an important factor. The lower leaves are always partially and varyingly shaded by those above and even average values would be complicated to assess and of doubtful significance. Even under laboratory conditions, investigations of effects of changing intensities of light present many difficulties.

With respect to duration the position is very much clearer. The normal seasonal variations are known to be of outstanding importance and the daily periods can be easily measured; for this purpose Brisbane data corrected for Buderim Mountain were used.

So far as temperature is concerned several aspects needed to be considered also. In the first place, there is no justification for assuming that Fahrenheit or any other thermometer scale has any direct meaning with respect to the banana plant. Initially then an attempt was made to calculate a banana scale, but none more satisfactory than Fahrenheit could be devised. This scale has at least one advantage in that its graduations are so small that it is markedly sensitive. The effect of temperatures must then be considered. Whilst the temperature coefficient (Q_{10}) for chemical reactions is high, in the case of purely photo reactions it is low. Q_{10} for photosynthesis varies with different light intensities but it appears probable that normally it lies between 1 and 1·4.

Whilst an attempt was being made to investigate a possible photosynthetic reaction it could not be assumed, at least at this stage, that ordinary photosythesis was being measured. However, the reaction being investigated is apparently of the same type as photosynthesis and, therefore, a tentative approach may be made through the known facts concerning photosynthesis. In the present work the range of temperature is from 55° F. to 90° F., i.e., approximately from 12·8° C. to 32° C. If then the number of degrees Fahrenheit is used as a direct multiple, the effect would be to record values of Q_{10} declining steadily from the lower to the higher temperatures and having a mean of almost 1·3 which, though lower than the values obtained by F. F. Blackman and his co-workers, conforms to those found by Willstätter and Stoll and the deductions of Brown and Heise (Miller, 1938). In the field all measurements are necessarily rather coarse and it was felt that in using degrees Fahrenheit in this way the facts would probably not be obscured, even though only approximations could be so obtained. For many biological studies mean temperatures are known to be quite inadequate and it was thus necessary to examine the position with respect to temperature incidence. Initially, therefore, an inspection of the temperatures was made by taking the readings hour by hour. It was found that the mean daily temperature did in fact give a very good indication of the conditions which had operated over that period. That is to say, the sum of the temperatures multiplied by the period over which they occurred was very close numerically to the mean temperature multiplied by the total period, a position which was expected since violent fluctuations were practically absent.

The Concept of Ts.

An approach to the problem was then made by combining in a multiple the area of each leaf, calculated as described above, the number of hours daylight to which each was exposed, and the mean temperatures operating over the functional life of each leaf. For the purpose of this calculation, when a whole month was involved the mean monthly figures were used. In this way for each leaf a series of multiples was obtained which gave a figure for each month, or other special period where desired. The sum of these multiples was for convenience termed Ts and thus the total Ts for any plant could be calculated up to any desired date.

Ts x Area of Leaf Produced.

Inspection showed that Ts gave no indication of possible budding date when considered alone. Following on from what had been ascertained concerning the combination of total area and area of a particular leaf, the factor Ts was then multiplied by the area of the latest leaf produced following the attainment of that Ts. When this was done, it was found that all the plants in the field trial gave a product of much the same magnitude at such times as the other evidence suggested budding should have taken place. The figures were then applied to the growth study plants and in every case the results were in conformity with what the dissections had revealed. It was found that in the growth study plants the largest which had not budded (A4) gave a product of 54,000 x 10^7, and the smallest which up to that time had been found to contain a bud gave a figure of 63,000 x 10^7. Following this, plant 21A (first ratoon) was removed from the field trial and dissected five days after it had attained a total of 56,000 x 10^7. The photomicrograph constituting Plate 13

Table 14.

Ts x Area of Leaf Produced.

Plant No.	Leaf Before Flowering.					
	14th.	13th.	12th.	11th.	10th.	9th.
1A ..	..	38,110	59,960	..	..	..
1B ..	..	..	46,050	57,220	..	..
2A ..	..	53,040	68,470	..	..	..
2B ..	..	45,520	59,800	..	..	..
3A ..	..	48,100	59,910	..	..	..
3B ..	..	38,790	51,120	58,480	..	..
4A ..	63,690	68,280	..	..	..	..
4B ..	..	..	50,810	61,760	..	..
5A ..	..	57,360	66,280	..	..	..
5B ..	..	49,950	61,810	..	..	..
6A ..	..	..	46,630	61,630	..	..
6B ..	..	..	..	41,530	61,160	..
7A ..	..	..	44,500	62,530	..	..
7B ..	..	49,830	65,460	..	..	..
8A ..	..	53,780	54,510	69,600	..	..
8B ..	..	47,140	70,250	..	..	..
9A ..	..	47,250	70,570	..	..	..

Table 14—continued.

Ts x Area of Leaf Produced.

Plant No.	Leaf Before Flowering.					
	14th.	13th.	12th.	11th.	10th.	9th.
9B ..	..	48,220	63,170	..	..	..
10A ..	..	50,388	64,480	..	..	..
10B ..	..	..	43,000	51,640	61,890	..
11A ..	..	..	50,630	69,810	..	..
11B ..	..	..	51,600	95,900	..	..
12A ..	..	..	30,990	35,330	49,150	63,800
12B ..	..	50,520	63,980	..	..	..
13A ..	..	52,910	69,040	..	..	..
13B ..	..	..	47,560	59,230	..	..
14A ..	..	..	36,160	43,320	49,840	57,560
14B ..	..	..	48,420	60,170	..	..
15A ..	..	..	58,010	..	..	..
15B ..	..	..	46,870	56,040	65,540	..
16A ..	50,310	62,700	..	..	..	..
16B ..	..	56,460	66,180	..	..	..
17A ..	..	..	45,260	50,940	82,900	..
17B ..	..	..	44,780	51,070	81,510	..
18A ..	..	..	43,130	51,510	60,230	..
18B ..	..	..	46,460	51,980	69,630	..
19A ..	..	..	..	..	57,120	69,740
19B ..	..	..	..	50,890	61,560	..
20A ..	..	..	..	55,670	64,890	..
20B ..	..	..	..	..	49,400	67,760
21A ..	..	..	46,540	60,270	..	..
21B ..	..	..	..	49,350	73,740	..
22A ..	..	..	..	46,280	60,330	..
22B ..	..	..	50,030	63,840	..	..
23A ..	..	..	50,900	53,700	47,800	64,880
23B ..	..	..	48,810	64,570	..	..
24A ..	..	42,760	62,740	..	..	..
24B ..	..	..	..	48,100	56,010	76,450
25A ..	..	..	48,440	72,230	..	..
25B ..	..	..	48,900	62,840	..	..
26A ..	..	46,810	65,330	..	..	..
26B ..	66,330	62,650	..	..	..	..
27A ..	..	..	53,830	68,600	..	..
27B ..	..	..	53,250	76,920	..	..
28A ..	..	..	53,500	53,210	75,750	..
28B ..	..	..	58,350	..	..	..
29A ..	..	53,160	74,290	..	..	..
29B ..	..	48,200	64,910	..	..	..
30A ..	..	..	34,610	41,650	66,580	..
30B ..	..	40,150	59,290	..	..	..
31A ..	..	..	54,000	70,390	..	..
31B ..	..	48,000	49,940	56,990	..	..
32A ..	..	44,460	60,260	..	..	..
32B ..	..	..	48,720	63,280	..	..

Each figure is to be multiplied by 10^7.

shows that this plant had a very slight elongation at the apex of the corm, the first evidence of the production of the sexual organs. The figure 56,000 x 10^7 was then adopted as the standard, and the result of applying it to each of the field trial plants is shown in Tables 14 and 15. The dates set down can be approximate only and have been chosen as those denoting the presumed time of differentiation of the last leaf of each plant.

Discussion of Results.—It will be noted that the table of dates (Table 15) as a whole bears out the results obtained in the dissection work. The numbers of leaves produced subsequent to the calculated date are, with four possible exceptions, in conformity with requirements. It will be seen that 13 plants subsequently matured nine leaves, for 14 plants the total was 10 leaves, for 22 plants 11 leaves, for 11 plants 12 leaves. Of the remaining four plants

Table 15.

BUD INITIATION DATE AS CALCULATED FROM Ts AND AREA OF LEAF.

Plant No.	Budding Date.	Flowering Date.	No. of Leaves Immature.	No. of Female Hands.	Treatment.
20A	Apr. 29	Oct. 24	9	6	N
19A	Apr. 29	Oct. 24	9	6	P
18B	May 19	Nov. 7	9	8	K
19B	May 19	Nov. 7	9	6	P
21B	May 20	Nov. 9	10	8	NK
24B	May 20	Oct. 31	9	6	NP
11B	May 20	Nov. 16	11	10	K
10B	May 24	Oct. 31	9	6	NPK
18A	May 25	Nov. 7	9	8	K
11A	May 25	Nov. 13	11	9	K
17B	May 25	Nov. 10	10	7	NPK
23B	May 25	Nov. 21	11	10	O
4B	May 26	Nov. 7	10	8	PK
3B	May 26	Oct. 31	9	6	NK
25B	May 31	Nov. 14	10	7	PK
29B	June 1	Nov. 21	11	9	NPK
22B	June 2	Dec. 5	11	10	PK
20B	June 5	Nov. 14	8	7	N
14A	June 8	Oct. 24	8	7	NK
15B	June 9	Nov. 28	10	10	O
7A	June 14	Nov. 28	10	9	P
14B	June 15	Nov. 28	10	8	NK
3A	June 16	Nov. 29	11	10	NK
22A	June 20	Nov. 21	9	7	PK
26B	June 27	Dec. 23	13	10	NK
4A	July 5	Dec. 23	13	10	PK
12A	July 5	Nov. 7	8	6	N
2B	July 11	Dec. 5	11	10	NP
8A	Aug. 13	Jan. 11	12	9	K
23A	Aug. 29	Dec. 16	9	9	O
10A	Sept. 2	Jan. 9	12	9	NPK
27B	Sept. 2	Jan. 2	11	8	NP
25A	Sept. 4	Jan. 9	11	10	PK

Table 15—continued.

Bud Initiation Date as Calculated from Ts and Area of Leaf.

Plant No.	Budding Date.	Flowering Date.	No. of Leaves Immature.	No. of Female Hands.	Treatment.
28A	Sept. 5	Jan. 2	10	9	O
9A	Sept. 9	Jan. 19	12	10	P
8B	Sept. 9	Jan. 15	11	8	K
32B	Sept. 11	Jan. 17	11	8	K
15A	Sept. 12	Jan. 13	11	8	O
17A	Sept. 16	Jan. 11	10	9	NPK
7B	Sept. 16	Jan. 20	10	8	P
26A	Sept. 19	Jan. 25	12	9	NK
27A	Sept. 23	Jan. 19	11	8	NP
30B	Sept. 23	Jan. 20	11	8	N
29A	Sept. 23	Jan. 28	12	9	NPK
16B	Sept. 23	Jan. 30	12	7	PK
5A	Sept. 25	Jan. 14	11	7	NPK
24A	Sept. 25	Jan. 15	11	9	NP
31A	Sept. 26	Jan. 20	11	8	P
12B	Sept. 26	Jan. 30	12	7	N
13A	Sept. 29	Jan. 30	12	8	NP
1A	Sept. 29	Jan. 16	11	8	O
9B	Sept. 30	Jan. 20	11	9	P
6B	Sept. 30	Jan. 9	9	8	N
16A	Oct. 1	Jan. 30	12	9	PK
30A	Oct. 2	Jan. 3	9	8	N
2A	Oct. 7	Jan. 30	12	8	NP
6A	Oct. 7	Jan. 20	10	7	N
13B	Oct. 9	Jan. 17	10	8	NP
5B	Oct. 17	Jan. 30	12	8	NPK
32A	Nov. 22	Feb. 27	11	9	K
1B	Nov. 22	Feb. 20	11	7	O
31B	Dec. 10	Mar. 5	10	6	P
21A	Dec. 10	Mar. 5	10	6	NK
28B	Dec. 13	Mar. 20	11	6	O

13 leaves and eight leaves were produced by each of two. At first sight these figures appear to fall into a normal distribution curve but the small number of positive whole numbers precludes an examination on that basis. It is of particular interest that of those plants which produced nine leaves subsequent to budding date all but three flowered before the end of November; and, as has been pointed out earlier, the dissections showed that the younger plants carried the lowest number of developing leaves. The flower invariably emerges quickly after the last leaf is unfurled and consequently the time taken from bud initiation to flowering is determined by the number of leaves which remain in an undeveloped condition at budding time. Hence there is no stable rate of flower development. Thus a number of apparent anomalies occur, as for example with plants 5A and 26A. It will be seen that the former plant reached the required standard six days later than the latter but a difference in the developmental periods results owing to 26A having to mature 12 leaves as against 11 in the case of 5A.

The apparent exceptions—4A, 26B, 12A, and 14A—may now be examined. The first possible explanation of the behaviour of these individuals is that errors have occurred, perhaps through the approximate methods used in calculations of Ts. It is, however, considered that this is not so, but that the facts are as correctly represented in these cases as in all others.

Though the maximum number of immature leaves found within the pseudostem was 12 this is scarcely sufficient reason for assuming that that number cannot be slightly exceeded; and as few as eight have been found in well-established plants, though in all such instances the plant was too young to admit of flower bud initiation being suspected.

The hands of flowers are placed in the axils of bracts, and as bracts are homologous with leaves it might be expected that the number of hands of flowers might bear some relation to the number of leaves developed over a like period. If reference is made again to Table 15 it will be seen that the number of hands of fruit is never greater than the number of leaves developed after the calculated budding date, and the average number of these hands increased as the average number of leaves increased. It will be noted that the four apparently abnormal plants fit quite well into this pattern, for 4A and 26B each bore ten hands of "female" flowers and 14A and 12A carried seven and six such hands respectively.

The relation between the number of hands of "female" flowers and the number of leaves developing after budding does not, of course, complete the account of the activities of the plants in this respect; for in addition to those flowers which are to give rise to fruit there are a very large number of other flowers, each group of which is subtended by a bract in the same way as the fruit-producing ones, and some of these have also reached an advanced stage of development by the time the inflorescence appears at the throat of the plant.

As has been recorded, the general trend is for the number of leaves being developed at any one time to increase with the age of the plant. Initially, of course, the number must be one or but very few. It would appear then that as the aerial stem elongates the rate of initiation of buds which are to give rise to leaves, or to leaf homologues, increases; so that if the number of these buds at any one time were plotted against the age of the plant the curve would commence towards unity, rise fairly rapidly at first, until the number reached eight, then rise at a very slow rate until some time after flower bud differentiation had taken place, and then once more rise steeply. That is to say, the curve would be sigmoid in type. *The flowers are budded in the axils of the bracts and it appears then that the flowers which are to give rise to fruit are differentiated before the final rise in rate. The later flowers are then budded in rapid succession, maleness being positively correlated with rate of budding.* This interpretation will be made clearer when the question of flower development is discussed later.

Botanical Interpretation of Budding Point.

It appears that change from the purely vegetative phase to that in which floral organs are developed must be caused by a change in the reactions involved

in growth and does not follow from the simple accumulation of material of any kind. It seems logical to look for a change in rate of some reaction. However, it will be remembered that when a factor for rate was sought through a measure of the daily production of leaf no positive result was achieved, but that a common suitable point was found when the area of the appropriate leaf was employed. If, therefore, rate is a factor it is evident that this rate is not to be computed on an ordinary time basis but in terms of plant activity. The concept, then, is that *the area of leaf gives a measure of rate within the plant, the period between the initiation of successive leaves being the only true measure of time.* Thus, the rate is to be determined not on how much leaf is elaborated per day throughout the growing period of the leaf but on the activity which the plant can bring to bear on one leaf before its resources must be transferred to the development of the next bud. The matter is discussed as though the plant shifts its total applicable resources from one point to another, but this has been done only for simplification and the same arguments would hold for a definite fraction of those resources. It may be pointed out that a slowing down in the rate of initiation of leaves should not be visualized. Though leaf bud initiation is not a simple nutritional effect the factors which control it have their influence also on growth in general, so that when leaf bud initiation is retarded so also is the activity upon which the size of the leaf depends. However, factors additional to those concerned with leaf initiation are of moment in determining meristematic activity and leaf size, and it appears that it is because of these other factors that the rate of leaf production as calculated failed to yield a satisfactory criterion of budding in all cases. Apparently for the majority of plants the two sets of factors concerned were more or less proportional at the time of budding and for these plants satisfactory results were accordingly obtained, whereas with the other the proportion was not sufficiently well maintained at the critical point.

The size of the leaf is determined, in the first place, by the meristematic activity associated with its initials, and it seems that the result of this activity is bound up to some extent with the length of time the meristem is functioning in respect to a particular leaf as well as on the intensity of the activity. In turn the length of time is under the control of factors external to the plant, as has been deduced in the early portion of the work. In the second place, the area reached depends on the conditions pertaining during the developmental period. The area of the leaf produced, then, gives a measure of the meristematic potential; and, since the greatest expansion takes place late in the development, this area also measures the effects of both internal and external conditions at this time. Since the plant in effect accurately and sensitively interrelates and integrates conditions, the area produced is a better measure of those conditions than could be obtained by the artificial measurement of each of the factors, even were all of these and their interactions known.

When considering this measurement of conditions it appears at first thought that a rather long period may be involved, but there are four points which may be cited:—1. As will be shown later (page 81), the correlation between size of leaf and Ts in the previous month suggests that it is conditions

late in its development which mainly influence the area of that leaf, for even though a leaf may have been initiated several months earlier there is a close relationship with conditions just prior to its extrusion. 2. Flower buds are developed not in place of vegetative buds but in addition to them, the vegetative (i.e., leaf) organs being modified to bracts and not eliminated. 3. The photomicrographs constituting Plates 14 and 15 show that flower buds of very much the same size are present in each of several successive axils and in view of this these buds must have been initiated in quick succession. 4. The development of the bracts in this early stage is considerably advanced as compared with that of the flowers and this suggests that flowers can arise in the axils of appreciably developed leaves. This means that though the conditions cannot be assessed until the appropriate leaf is extruded they have had their effects on the oldest affected buds some little time before that extrusion. That expansion in the later stages of leaf growth may be due largely to water uptake is probably a significant point.

The position may then be explained as follows:—A new leaf is budded and the meristematic activity of the plant is concentrated on the laying down of tissue for that leaf until such time as external factors cause a diversion of materials and energy to the laying down of the following leaf. As has been pointed out, the mere ability to produce a leaf of large size is not associated with the initiation of the sexual phase. The Ts is also of moment, and theoretically if a plant of Ts 28 producing a leaf of size 2 were able to bud, so also would a plant of Ts 14 producing a leaf of size 4, whereas one of Ts 10 giving rise to a leaf of 5 units would fail. The initiation of the flower bud is associated with reactions which occur in one small section of the plant. Other meristems are not affected, for the suckers do not commonly bud at the same time as the parent plant. This suggests the accumulation of some product probably in the vicinity of the apical meristem; and, further, that this product is accumulated at a rate proportional to the Ts as calculated. This accumulated product apparently influences growth reactions to a degree proportional to the conditions as measured by the area of leaf being produced. For simplicity it may be taken that temperature is the particular condition, though it is certain that the factors are complicated. If there is such an accumulation then the material must act as either an activator or a stabilizer. There is no reason to assume that the action is chemical any more than that it is physical. All that can be said is that the effect is governed by the same conditions as influence leaf growth. For explanatory purposes the action may be visualized as in the nature of a pressure with the activator as the energy-controlling medium. The "pressure" is in proportion to the amount of activator present as measured by the Ts, and as with a gas can be increased either by increasing the medium or the "temperature." If then, "pressure" exceeds a particular value the directions of the reactions are altered so that floral parts are developed. That the "pressure" may be measured in terms of an electric potential seems possible. As Thatcher (1921) points out, "many of the phenomena of nature are colloidal in character" and "the regulation of the passage of materials into and out of the cell is governed by minute change in electrolyte concentration, &c., which produce

enormous changes in the colloidal character of the protoplasm.'' The mechanisms of the reactions, however, are of secondary importance in this work, which is concerned primarily in assessing the validity of the calculated budding point and assuring that a reasonable explanation of the events can be given.

Research in recent years has focused attention on the subject of plant hormones, and whilst much confirmation of results reported and extension of the work are needed there is no doubt that certain substances in plants can act in the nature of hormones. Sachs (quoted by Maximov, 1930, p. 352) in 1883 noted that cuttings of begonia and other plants taken from blooming individuals flowered more quickly than those taken from non-blooming ones. These results have been confirmed by many other workers. Concurrently with this investigation on bananas, observations were made on papaw (*Carica papaya* L.). It was noted that invariably the grafted tree fruited at least two months earlier than seedlings planted at the same time. This represents a reduction of approximately 25 per cent. in the period to fruiting. The scions used were the side shoots of advanced bearing trees. The size of these shoots was, of course, a very small fraction of the trees produced from then up to fruiting time and yet apparently within their compass was sufficient of some substance to cause a reduction of 25 per cent. in time to flowering. Such a happening strongly suggests the influence of a hormone.

Sachs postulated the presence of a ''flower-forming substance'' and recent work on hormones appears to have inclined many towards this view. The observations on the banana here recorded do not require the presence of a special ''flower-forming substance'' for their explanation, but can be interpreted as readily by assuming that the same substance which promotes growth in the meristematic regions during the purely vegetative phase has a different influence when its effects exceed a certain figure (time x amount) ; just as the end products of some chemical reactions are varied according to whether concentrated or dilute acid is used or as the speed of the reaction may influence the course it will take, particularly when complex organic compounds are involved. It will be remembered that flower and bract formation alternate and thus some fluctuation in the effective ''pressure'' seems possible, suggesting the using up of some material or energy followed by a transient deficiency, or alternatively the temporary accumulation of an inhibiting substance having a buffering effect.

Carbohydrate: Nitrogen Ratio.

The ratio of carbohydrate to nitrogen has been given a great deal of attention in connexion with its influence on the initiation of sex organs in plants and it is, therefore, of interest and importance to examine the results which have been obtained in this study from the point of view of the C:N ratio.

Whilst the uptake of solutes from the soil and the utilization of these by the plant are not to be taken as proportional to the amount of water entering the plant from the soil at any time, there can be no doubt that the amount of nitrogen which enters through the roots is governed to some extent by the water supply; and the general metabolism within the plant is likewise dependent to

a degree on temperature. Further, though the rate at which a plant can utilize nitrogen in the synthesis of proteins and other complex compounds may be determined by the early uptake of mineral nutrients, this does not necessarily mean that all the uses to which the plant can put nitrogen are similarly fixed. The amount of nitrogen which can be detected in plants fluctuates almost continuously. The availability of this element to the plant depends in two ways on soil moisture. In the first place, of course, the amount of water transpired by the plant is affected; and in the second soil moisture in conjunction with temperature has a profound influence on the biological and chemical processes involved in the production of nitrate and other nitrogenous compounds which can be utilized by the plant. It has been shown that there is a close connexion between temperature and soil moisture, as external factors, and leaf initiation; and in view of the well established effect of nitrogen supply on the leafiness of other plants the explanation of leaf initiation may lie in the uptake of nitrogen. When the change from leaf bud to flower bud initiation takes place the meristematic activity has been centred in one position over a comparatively long period, i.e., the initiations of two successive buds have been sufficiently spaced in time to allow the change to be effected. Thus so far as leaf initiation is concerned there has been either a slowing down or more probably a failure to accelerate to the potential rate of initiation having regard to the capabilities of the plant. That is to say, it is possible that the nitrogen supply may have been insufficient to allow of another leaf bud being laid down with the rapidity necessary for the maintenance of normal vegetative growth. Thus a comparative lowering of the nitrogen status of the plant may be visualized at the time of flower bud initiation.

Further, at the time of flower bud initiation the Ts and, as will be shown below, perhaps the carbohydrate status of the plant are high. Thus a widening of the carbohydrate : nitrogen ratio is a possibility and the budding of the banana may thus be capable of interpretation in harmony with the chemical results obtained by Kraus and Kraybill (1918).

Although these observations on the banana are perhaps capable of interpretation in terms of the widening of the C:N ratio no such conclusion is warranted solely on the facts elucidated in the course of this investigation; and all that can be claimed is that the photosynthetic potential is high when effects of factors such as temperature and soil moisture, on which the supply of nitrogen also depends, are comparatively low. The results obtained by D. T. MacDougal, as recorded by Miller (1938, p. 1020), on the influence of colloidal hydration on growth suggest that it may even be the water itself which is the limiting factor and the nitrogenous or other material it carries merely incidental. A chemical analysis of the plant at this time would, therefore, not necessarily further our knowledge, for even though a low nitrogen content were found it would prove nothing.

Evidence on Bud Initiation in Fruit Characters.

The general characteristics of bunches "thrown" at different times of the year are well maintained, so within limits an experienced man can tell from

general appearances approximately at what time of the year a particular bunch first appeared. Thus a typical September bunch carries compactly placed hands of even, strongly curved fruit; whilst a January bunch bears long, widely-spaced fruit and presents a very open appearance.

The most characteristic of all bunches is the so-called November "dump". In this bunch the main feature is the numerous small, squat fruit. This type of bunch is almost invariably the only type produced during the first part of November and is not repeated at any other time of the year. This is commonly a month of low rainfall but that would not explain the yearly occurrence of this type of bunch; for the month is not invariably a drought one and, further, bunches thrown at other dry times do not exhibit the characteristic dump fruit. The factor which causes the shortening of the fruit is obviously of more regular occurrence than rainfall. An examination of the field trial plants showed that all bunches which were calculated to have been initiated before June 16 carried dump fruit. It will be seen that these buds experienced lower temperatures during their development than obtained at the time of their differentiation. Other plants budded at lower temperatures but did not carry dump fruit. From this it appears that when buds are initiated under one set of conditions they are checked if subjected to less congenial ones, whereas those which commence under the most adverse conditions are not so affected. Early April buds, which would give rise to October bunches, apparently are too far advanced in their development to suffer the same check though they must pass through the same rigorous conditions.

From all the evidence it is considered that the bud initiation date can be calculated by the use of the product of Ts and the area of leaf produced at a specific time and for the field trial plants is approximately as shown in Table 15 (pages 69-70). It will be seen that the validity of the date is by no means undermined by results obtained by its use. The drop in the efficiency in growth index, referred to earlier, also points strongly to the validity of the deductions.

THE INTERPRETATION OF Ts.

As has been shown, the factor Ts can be employed in the computation of the time of initiation of the flowering stage in the banana. It is, therefore, advisable to examine this factor and ascertain whether it has significance in some more fully understood phase of plant activity.

Relation to Photosynthesis.

The contributing factors which have been used in calculating Ts are of outstanding influence in photosynthesis also. However, photosynthesis is a multi-conditioned process and it is scarcely practicable in a field experiment to assess accurately and take into account more than two or three of the principal factors involved. The factors may be divided into environmental and internal, though in some cases even this broad division is not entirely satisfactory. A great deal of research has been done on the subject but the meaning of many of the results is far from clear; and obscurity is a feature of much of the work,

since so much conflicting evidence is forthcoming. Stiles (1925) lists 14 factors which influence photosynthesis and some of these are in themselves somewhat complex and many are closely interdependent. Of the external factors involved in the process carbon dioxide concentration, light, temperature, and water supply, may be taken as of outstanding importance; whilst the chlorophyll content of the leaves is a major factor within the plant. These factors can be discussed in relation to Ts.

The Light Factor.—With respect to light, both intensity and duration are of moment and, as has been pointed out, the measurement of intensity with respect to all the leaves offers great if not insuperable difficulty. Although there can be no simple relationship between intensity and duration it appears probable that if the duration is taken into account some measure is being made of average intensity also. So far as duration is concerned two points at once appear. In the first place, under natural conditions temperature and hours of daylight are closely and positively correlated, long days being invariably associated with high temperatures and *vice versa*. Thus in the absence of control of one of these factors it is difficult to separate out the individual influences, except perhaps over a long period of years, by the use of such a method as partial correlation. In the second place, some plants are able to elaborate in but a fraction of the day all the carbohydrate that can be dealt with by them. It has been observed on many occasions that banana plants, in situations in which the length of day is in effect shortened, grow more slowly than others exposed to the sun for the maximum possible time. Such an effect quite commonly happens where high ridges or belts of tall trees cause shading of portion of the area in the mornings or afternoons. In these circumstances it was concluded that in all probability the banana was able to photosynthesize over the whole period of daylight; for though in many cases one result of shading is a lowering of temperature, in many others this is not the case, as, for example, where there is notable reduction in air movement giving rise to particularly hot conditions in the valleys between ridges.

The Temperature Factor.—Temperature has been discussed to some extent in connexion with Ts and what has been stated there refers also to its place in respect to photosynthesis. However, temperature influences assimilation in several ways; and can, in fact, be regarded as a "master factor," affecting as it does photosynthesis, respiration, transpiration, stomatal movement (thereby influencing CO_2 supply), and supply of nutrients, particularly nitrogen. The effect of temperature is, of course, not the same on each of these factors concerned in growth, though broadly speaking within the normal range its final effects are at least in the one general direction; i.e. increase in temperature is positively correlated with increased growth. It should be pointed out that in dealing with all of these phases it is not the temperature at any one time which is to be considered. Thus it is daylight temperatures which influence photosynthesis whilst night temperatures are of particular concern with respect to that respiration which proceeds during hours of darkness. Further, the temperature which affects nitrogen supply is at least partly a soil one. However,

under natural conditions in the area in which the work was carried out violent fluctuations are rare. An examination of Figure 23 shows the correlation between mean day temperatures and mean night temperatures. It will be seen that there is a close relationship between the two and this will be appreciated particularly when it is known that the points are selected from every month of the year and thus represent disjoined periods. If a continuous period is used the relationship must improve. From this it seems that whether mean daylight

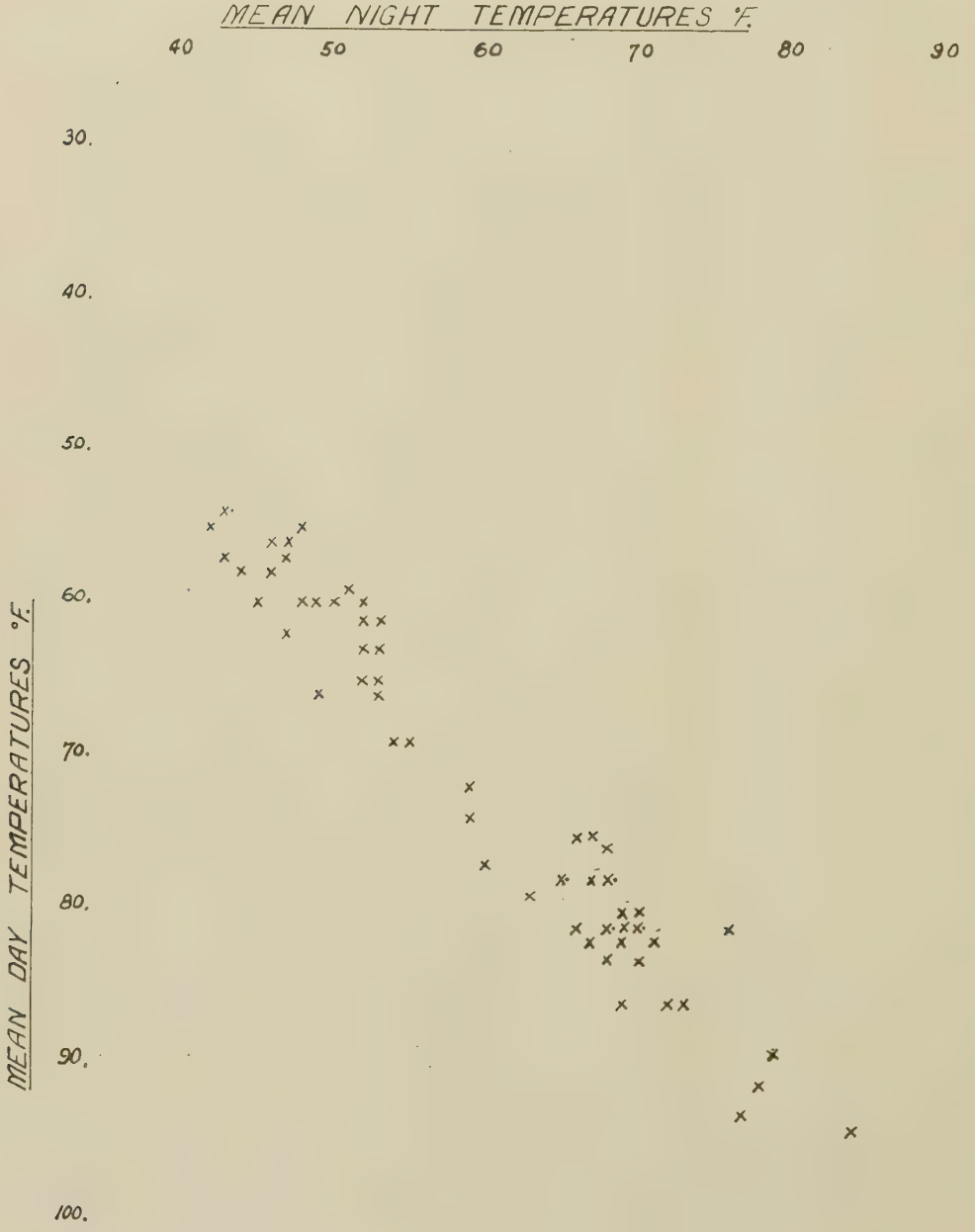


Fig. 23.—Showing Relation between Mean Day Temperatures and Mean Night Temperatures.

temperature, mean night temperature, or mean daily temperature is used, a measure of each of the others would actually be employed.

CO_2 Concentration.—No measure of CO_2 concentration was carried out and all that can be said of this compound is that, considering the site of the experiment, the fluctuation of the amount in the air would certainly be small and the concentration was taken as constant. In this latitude seasonal differences would be expected to be very small.

Supply of Water.—An attempt was made to incorporate soil moisture data but several difficulties soon presented themselves. The soil is lateritic and in common with others of this class its moisture relationships are very obscure. For example, wilting point determinations were made and the results varied between 14 per cent. and 24 per cent. according to the technique employed. Maximum field capacity was consistent but this point is of less interest in this work. Until a wilting point can be established it is scarcely possible to learn a great deal about the usage of water by the banana or safe to employ soil moisture measurements in the calculations. At no time did the plants show any distress, and whilst there was no doubt great variation in soil moisture during the progress of the growth of the plants it appeared that the soil moisture remained above wilting point throughout.

General Considerations.—Gregory (1926), following experiments with barley plants under controlled moisture conditions, stated:—"It may be said that net assimilation rate is almost completely controlled by the factors of temperature and radiation . . . ." and again, "control of net assimilation by temperature and light is almost equally close, and in general neither one nor the other can alone be limiting the process over any considerable period of time." Most of the curves which appear in the literature showing the relationship between CO_2 concentration and photosynthesis, temperature and photosynthesis, and light and photosynthesis, are either straight lines or exhibit but slight curvature over the normal range. As has been stated, in this work the temperature range was between 12° C. and 32° C. In her work Miss Matthaei found an almost linear relationship between temperature and photosynthesis up to about 25° C., and most investigators agree that for temperate climate plants the almost linear relationship holds at least until the temperature is in the vicinity of 30° C. There remains to be considered, however, the "limiting factor" hypothesis as conceived by Blackman (1905). Spoehr and Smith (in Duggar, 1936) state:—"In recent years the effect of light intensity on the photosynthetic process has been extensively investigated. The experiments show that the 'limiting factor' or Blackman hypothesis can never be fully realized and can be approached in only a few cases." Optimum and limiting values can scarcely be fixed points, depending as they do on a multiplicity of interdependent variables, and thus they lose something of their significance in practice. Whilst Blackman's thesis must be given every consideration, it appears possible that in normal conditions the limit points will not be encountered. The points are known to differ with different species of plants and in general it is to be expected

that each of these points would be highest in tropical species. In the case of this investigation, one species of plant growing well within its climatic range is being dealt with and the temperatures are known to be far removed from the maximum that the plant can withstand. With respect to the minimum, much of the evidence obtained suggests that, whilst growth is very slow below 40° F., the lower limit of growth is appreciably below that point. The low temperatures encountered were generally above 50° F., and actual minima in the vicinity of 40° occurred very seldom and always as night temperatures.

In calculating Ts a linear relationship was assumed for each of the factors as it was felt that, if the curvature were marked and capable of being truly estimated, or if a distinct break in the curve lay appreciably within the range being investigated, the data would fail to give leads which would otherwise be expected.

As has been shown Ts is arrived at by combining a number of the more important factors concerned in growth, particularly so far as this is fundamentally dependent on photosynthesis; and Ts may, therefore, possibly give an approximate measure of the ability of the plant to elaborate carbohydrate under the varying conditions which it has experienced. In the absence of stresses, such as may be caused through a deficiency of some nutrient material for example, it may be assumed that the metabolism generally is consistently proportional to that ability; otherwise physiological disorders would arise. It must, of course, be emphasized that long term changes only are being considered and the measurements are too coarse and the omissions too many to permit of precise data being obtained or minor fluctuations being measured; and it is factors which have been assessed rather than effects. It remains to be determined how far this assessment of potential can be interpreted in terms of results.

In giving consideration to the component parts of a growing plant a rigorous demarcation between cause and effect in the process of growth is largely a matter of the time at which the examination is being made. Thus, by virtue of its capacity to grow, the plant may produce a leaf and immediately the development of this leaf is completed the organ becomes a factor in the further growth of the plant. The position is obvious in the case of the leaf but it is equally true of all other vegetative parts, though the manner of working may be less direct or more obscure in some cases. It is true that some of the final products of growth, even whilst the plant is wholly vegetative, may contribute nothing to the increase of the plant, as, for example, secretions such as waxes, resins and gums; but normally, in the absence of injuries or other factors which may disturb metabolism, such products as these are produced in proportion to the amount of growth. If, then, a measure of the total growth up to a particular time can be obtained quantitative information is at once available as to the plant's future capabilities. What is true of the whole must also be true of the parts, so that if a measure of the total photosynthate is obtained the ability of the plant to react to environmental influences should be proportional to that figure. If the immediate photosynthate is taken as carbohydrate it does not directly follow

that the amount of carbohydrate present in the plant at any one time is proportional to the total photosynthate up to that time, since further elaboration has taken place. At the same time as the elaboration proceeds new leaf is produced and the capacity of the plant to photosynthesize also advances, so that whilst the proportion may change with time the mean amount of carbohydrate or other intermediate product of growth will tend to increase as the accumulated products of growth increase.

Correlation of Ts and Growth.

From the above it appears possible that, though all the factors influencing assimilation and more particularly the interactions between factors have not been given consideration, Ts may still give an approximate measure of the assimilation under the conditions in which the plants were grown. Commonly the best method of approach to a problem concerning amount of growth is by use of the weight of plant material produced; but in this work, since dry weights are required, this method could be used with a few plants only. It has been established that leaf growth also is quite often a very good measure of growth and this avenue was therefore explored. Before attempting to establish any correlation between Ts and leaf area it is necessary to point out certain facts so that the validity of the calculations will be clear. In the first place, the Ts in each case is being correlated only with areas which do not form part of factors used in the calculation of that Ts but which were the total areas produced in the month subsequent to its attainment. Secondly, the total area of leaf produced by the different plants differs, so the area which is still to be produced is not a specific total area less that already produced. Thirdly, the correlations are made over stipulated sectional periods and not over a particular fraction of the life of the plant. In a previous section it was shown that there existed some relationship between the area of leaf actually on a plant and the amount of leaf produced at about that time. In this present section, however, the relationship concerned is that with a summation of all the areas which had appeared at any time prior to the specific month named. Correlations then were looked for between the Ts up to the end of the month and the area of leaf produced during the following month. The Ts of each plant was calculated as at the last day of each month. In computing the area for the following month, as it was only rarely that the plant extruded a leaf on the last day of that month it was generally necessary to estimate the amount of leaf produced. This was done by giving consideration to the area of leaves produced just prior to and immediately after the relevant day and the period elapsing between the extrusion of these leaves. For example, if the position on September 30 were being examined and the plant had produced a leaf on September 26 and one measuring 600 square inches on October 4, this would be construed as meaning that by September 30 an additional 375 square inches (i.e., $\frac{5}{8}$ of 600) had been produced over the total at September 26. When fractions occurred in the calculations they were allotted according to whether the areas of leaves at the time were increasing or decreasing. The results are shown in Tables 16 and 17. It will be noted that the plants were grouped according to whether or not they were calculated to have commenced flower bud development, and in this connexion

Table 16.

CORRELATION BETWEEN Ts UP TO THE END OF EACH MONTH SHOWN AND AREA OF LEAF PRODUCED DURING FOLLOWING MONTH (BEFORE FLOWER BUD INITIATION).

Month.	D.F.	r	$\bar{y}$	$\bar{x}$	b
1. March	14	·8800	946	320	2·376 ± ·343
2. May	8	·9450	766	464	1·373 ± ·168
3. June	6	·8847	723	651	·857 ± ·184
4. July	7	·9646	484	689	·713 ± ·074
5. August	7	·9324	527	577	·592 ± ·087
6. September and October	5	·9606	874	753	·435 ± ·018

those plants were omitted which were believed to have budded within one month of the appropriate date. Similarly plants which flowered in a particular month were not included in the calculations for that month. The tables show the correlation coefficients, the means, and the regression coefficients. All correlations in Table 16 were found to be highly significant. The correlations are less marked in the case of plants which have budded and particulars of these are given in Table 17. The regression equation is of the form $Y - \bar{y} = b\,(x - \bar{x})$. The influence of climate is indicated in the means (y).

Table 17.

CORRELATION BETWEEN Ts UP TO THE END OF EACH MONTH SHOWN AND AREA OF LEAF PRODUCED DURING FOLLOWING MONTH (AFTER FLOWER BUD INITIATION).

Month.	D.F.	r	$\bar{y}$	$\bar{x}$	b
1. May	4	·9153	1,161	845	·931 ± ·205
2. June	15	—·1046	1,005	937	— ·039 ± ·095
3. July	14	·0912	783	1,172	— ·040 ± ·117
4. August	14	—·0628	942	1,412	— ·027 ± 1·114
5. September	4	·8529	1,054	1,359	·462 ± ·158
6. October and November	6	·9108	1,161	1,124	·655 ± ·121

As has been indicated the correlations after bud initiation are less marked, being now non-significant for June, July and August, significant for May and September, and highly significant for October-November, these last two months being grouped in order to obtain sufficient numbers of plants. The explanation of this lack of correlation in certain months after budding is probably to be found in the differences caused by variation in the degree of development. Once the plant has budded it is devoting portion of its energy and material to the production of parts which do not contribute to the further building up or maintenance of the plant. Though all the plants were calculated to have budded the initiation has taken place at various times, and thus the plants are not strictly comparable as they were when all were purely vegetative. The variation tends to decrease in the later months, for those which were more advanced have been removed from the calculations, and in these late months significance can again be attached to the correlation. This contention is supported by the results

for May, for the small number of plants used in that calculation are known to have budded at about the same time and would be in approximately the same stages of development throughout.

It may be pointed out that the correlations hold only within months and no relationship exists between months in respect to these figures. At the same time if the means ($\bar{y}$) be plotted against temperature it is found that a good linear relationship exists within each set of figures.

Further evidence was sought from the small number of plants in the growth correlation study but, as has been pointed out, many of these were necessarily destroyed in their early stages; as the number originally was only 36 figures from this section of the work alone cannot be very convincing.

If reference is made to Table 4 (page 13) it will be seen that plants E1 and A4 were greatly at variance in the figures given, for though the weights of corm are very similar the area of leaf produced by the former was only 10,400 square inches whereas A4 had produced 15,900 square inches, giving ratios of corm weight to area of 1 : 116 and 1 : 166 respectively. When the persistence of leaves is considered, however, in the case of E1 the total day-square inches was 834,000 whilst for A4 the total was 862,000. The growth of these plants took place at about the same period of the year so that the introduction of the mean temperature x daylight factor makes little difference. For instance, with D3 and B4, which grew concurrently, the areas are 15,500 and 16,600 square inches respectively and the day-square inches were 1,702,000 and 1,750,000 respectively. Plants A1 and B4 show weight to area ratios of 1 : 110 and 1 : 161 but the day-square inches were 1,342,000 and 1,750,000 respectively, which gives ratios of weight of corm to this factor as 1 :82 and 1 :85. When the further refinement of temperature x daylight hours is applied the ratios come still closer together, being then 1 : 9·0 and 1 : 9·1. An examination of all the growth study plants revealed that when all the factors included in Ts were applied the ratios of corm weight to the multiple lay between 1 : 8·75 and 1 : 9·20 in every case.

It would appear, then, that under the conditions of this investigation Ts as calculated is an approximate measure of assimilation. If, as had been visualized, a growth substance is involved in bud initiation it appears reasonable to conclude that this is formed in proportion to the total photosynthate and that it is in fact a normal plant product.

It does not follow from this work that net assimilation of a plant could commonly be measured in the manner used for Ts, and in other circumstances the investigation should perhaps be directed towards a computation of net assimilation in a more exact and direct way.

SECTION 4.

DEVELOPMENT OF THE PLANT.

With the information which has now been obtained it is possible to make a survey of the main points in the life history of the plant. Whilst development and growth cannot be divorced, the terms are nevertheless by no means synonymous; and, if the broad principles of nutrition are to be understood, the difference between the two must be kept in mind. The development of the banana can be divided conveniently into three main stages based on the dominant activity over well defined periods. The commencement of one stage, however, does not mean the cessation of the previously dominant activity but merely its relegation to a place of less vital importance.

Stage 1.

The first stage occupies the time between the establishment of the plant as an independent entity and the initiation of the development of the floral parts. Before this establishment the plant, which arises asexually, is dependent to a gradually decreasing degree on the food which the "parent" plant provides. Initially it is thus parasitic in the widest sense of that term and its growth depends on its ability to make use of the material provided by the parent. It is, however, as an independent plant that it is being considered here and as soon as that condition is reached the first stage is commenced. During this period vegetative increase is the only manifestation of its activities.

Stage 1 may be divided into two sub-stages though the end point of the first is perhaps not very sharply defined. The initial sub-stage may be termed the formative one. It is of short duration, probably less than three months in the case of the experimental plants, and is a period of large relative increase. When the plant is separated from its parent corm it immediately commences to adapt itself to its environment, the first roots being pushed out into the soil to absorb nutrient material. It appears that it is during this stage that the apical meristem is developed, and the growth of the plant from then on is virtually determined by the amount of meristematic tissue laid down during this period. From the nutritional point of view it has been noted that the useful uptake of certain elements, notably potassium, is determined during the initial sub-stage. This would probably be more correctly stated by saying that to the amount of potassium and probably other mineral nutrients taken up in this sub-stage is fundamentally attributable the amount of growth subsequently made by the plant in any given period of time. Thus the development of the meristem is closely associated with the uptake of nutrients at this time. The evidence suggests that the end point of this sub-stage is associated with the production of a certain leaf area rather than with a period of time.

The plant then enters the second sub-stage during which vegetative increase proceeds at a rate governed by internal factors, the basis of which has been laid down in the first sub-stage, and external influences, particularly climate

and factors partially controlled by climate. The rate of increase, measured as a percentage of previous growth, is remarkably constant for different individuals under any one set of climatic conditions. The absolute increase in various individuals may, of course, vary greatly. The relationship of the absolute

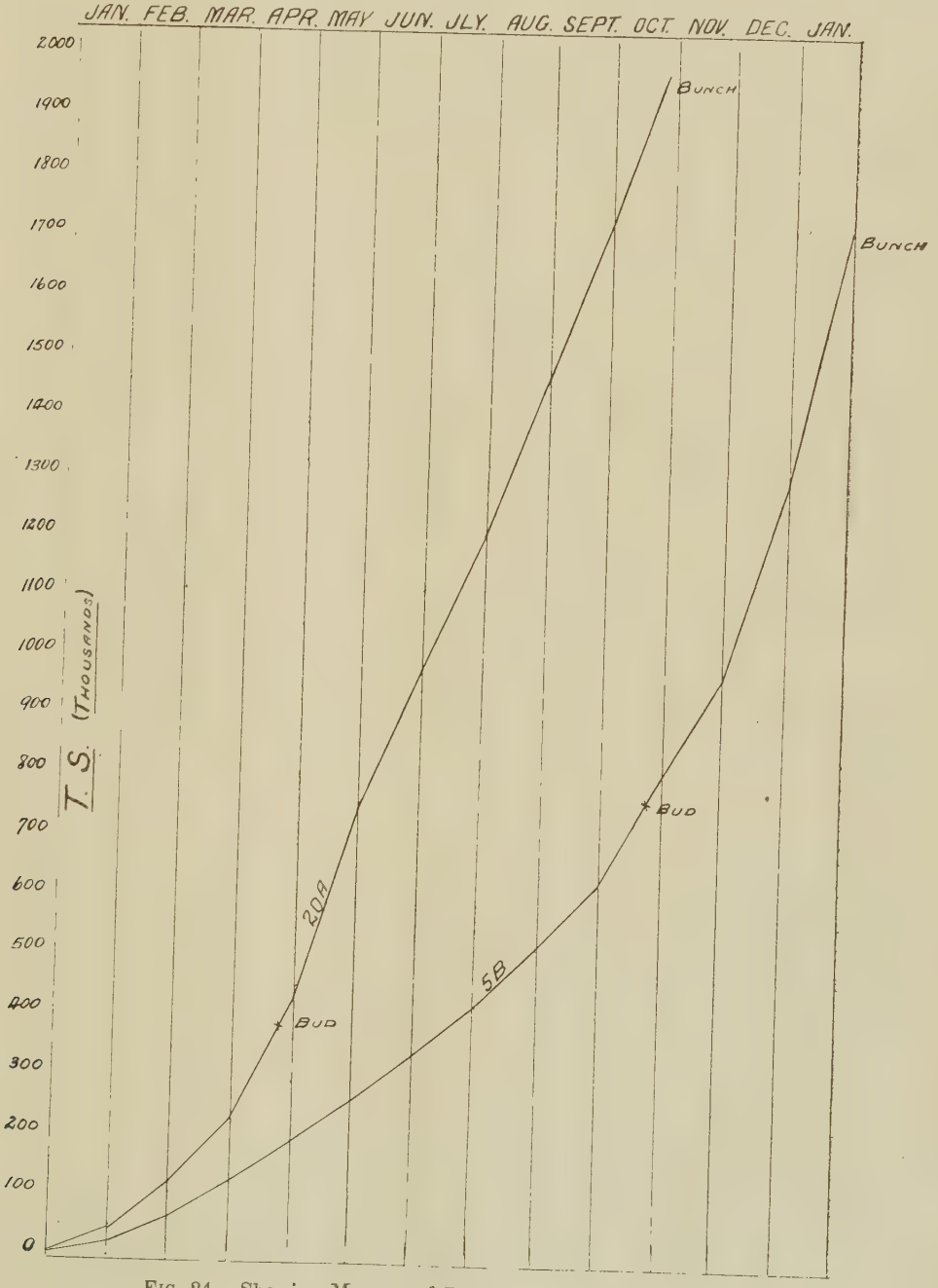


FIG. 24.—Showing Manner of Increase in Ts. of Two Plants.

increase to the previous history of the plant has already been fully discussed. During this sub-stage the plant completes approximately half of its total leaf area but this does not mean that half of its total growth, as measured by Ts, is likewise completed; for the latter depends partly on time and factors associated with time. Almost half the size may be reached or less than one-quarter may be attained. Figure 24 portrays the manner in which the Ts of two plants increase throughout their growing periods. This stage is wholly vegetative and its termination is marked by the initiation of the sex organs. In Table 18 are given the relations between the areas of leaf unfurled during Stage 1 and during the remainder of the growing period.

Table 18.

RATIO OF AREA UNFURLED DURING STAGE 1 TO AREA UNFURLED LATER.

Plant No.	Ratio.	Plant No.	Ratio.	Plant No.	Ratio.	Plant No.	Ratio.
1A ..	1 : 1·2	9A ..	1 : 1·1	17A ..	1 : 0·9	25A ..	1 : 1·0
1B ..	1 : 1·2	9B ..	1 : 1·1	17B ..	1 : 0·8	25B ..	1 : 0·7
2A ..	1 : 1·3	10A ..	1 : 1·1	18A ..	1 : 0·7	26A ..	1 : 1·4
2B ..	1 : 0·9	10B ..	1 : 0·7	18B ..	1 : 0·7	26B ..	1 : 1·2
3A ..	1 : 0·9	11A ..	1 : 1·0	19A ..	1 : 0·7	27A ..	1 : 0·9
3B ..	1 : 0·7	11B ..	1 : 1·0	19B ..	1 : 0·7	27B ..	1 : 0·9
4A ..	1 : 1·2	12A ..	1 : 0·5	20A ..	1 : 0·8	28A ..	1 : 0·9
4B ..	1 : 0·8	12B ..	1 : 1·2	20B ..	1 : 0·7	28B ..	1 : 1·3
5A ..	1 : 1·1	13A ..	1 : 1·4	21A ..	1 : 1·2	29A ..	1 : 1·3
5B ..	1 : 1·4	13B ..	1 : 1·1	21B ..	1 : 0·8	29B ..	1 : 0·8
6A ..	1 : 0·9	14A ..	1 : 0·5	22A ..	1 : 0·7	30A ..	1 : 0·8
6B ..	1 : 0·8	14B ..	1 : 0·8	22B ..	1 : 1·0	30B ..	1 : 1·1
7A ..	1 : 0·8	15A ..	1 : 1·1	23A ..	1 : 0·8	31A ..	1 : 1·1
7B ..	1 : 1·3	15B ..	1 : 0·8	23B ..	1 : 0·9	31B ..	1 : 0·9
8A ..	1 : 1·1	16A ..	1 : 1·3	24A ..	1 : 1·2	32A ..	1 : 1·2
8B ..	1 : 1·2	16B ..	1 : 1·3	24B ..	1 : 0·7	32B ..	1 : 1·0

Stage 2.

During the period occupied by the second stage the floral organs are developed. No foliage leaves are initiated but the development of those which have been differentiated before the close of Stage 1 is carried to completion. The aerial stem is commenced and reaches the top of the pseudostem. The continued increase in the weight of the rhizome and in the dimensions of other parts shows that vegetative increase continues at much the same rate, relative to climatic conditions, as has been the case during the previous stage.

Stage 3.

The third and last stage is ushered in with the unfurling of the last leaf and the thrusting forth of the inflorescence from the throat of the pseudostem. No further foliage leaves are developed and photosynthetic activity passes its maximum and gradually diminishes so far as it is controlled by the plant. On the other hand the development of the ovary and other floral parts is accelerated. The leaves die in succession, roughly in the order in which they were produced

with the possible exception of the spade leaf, which quite often dies early. By the time the fruit is mature the number of leaves may be reduced to one or two on even well nourished and protected plants. After maturation of the fruit the plant soon perishes as has been described earlier.

DEVELOPMENT OF THE FLOWER.

When the inflorescence emerges from the throat of the plant it is found that the basal hands have already developed ovaries of considerable size (Plates 21 and 22) and the degree of development of these organs decreases progressively from the base towards the apex. The bracts which have protected the flowers during development lift in acropetal succession. The proximal ones lift very rapidly and the rate of lifting diminishes as the stalk elongates. No fertilization takes place, so the development of the ovary receives no stimulus from any outside source but depends wholly on the plant which carries it.

It has been noted that the number of hands which give rise to marketable fruit is never in excess of the number of leaves still to be developed after the time of flower bud initiation. The connexion between the two has already been dealt with in part. The explanation of the disparity of numbers of hands of "female" flowers probably lies in the acceleration of bract development. The order of appearance of flowers is never varied, the quality of femaleness being always most in evidence in the basal hands and maleness in the higher placed ones. Further, the largest ovaries—that is, the largest fruit—are towards the base of the bunch though there may be some slight variation of order in this respect. However, as all the flowers are initially potential hermaphrodites, it may appear that to some extent femaleness and food supply are positively correlated. Sex is referable to the development of various organs and is not to be construed as meaning simply the size of the ovary. As has been shown, the total number of leaves and their homologues in the immature stage at time of flower initiation may be as high as 16 or 17, but if the inflorescence is examined within a few days of extrusion from the throat it is found that hundreds of bracts are present in various stages of development and the apex still presents very much the same appearance as it did when the first flower bud was differentiated. The acceleration in the budding of the leaf homologues is thus apparent. *It seems that the femaleness may be connected with the length of time the plant "concentrates" on the development of the flower bud,* in much the same way as the initiation of the flower is brought about in the first place as postulated earlier. This would explain the rather sudden transition from "female" to "hermaphrodite" flowers (Plate 23) whereas such a sudden diminution in the supply of food can scarcely be visualized. The leaves are carried up on the flower stalk and yet the last leaves, excepting the spade leaf, are quite frequently the largest the plant produces. Translocation difficulties, therefore, cannot be taken as the determining factor. The lessening effect on the activity of the meristem by the shortening of the time it is operating in respect to any particular set of flowers would further be accentuated by the gradual diminution of these meristematic tissues which are used up in the process.

Plate 20.

Plate 21.

Plate 22.

Plate 23.

[*For explanation of Plates* 20-23, *see page* 51.

Any disparity in the number of hands of fruit produced, as compared with the potential number calculated from the number of immature leaves, cannot be accepted at face value; for, as has been pointed out, femaleness is not indicated only by the size of the fruit and it is quite evident that in many bunches the "females" do not always fulfil their mission of producing marketable fruit. In many bunches several flowers on even the lowest hands may fail to develop ovaries of appreciable size, whilst the higher hands may be found to carry but a small proportion of fruit-producing flowers. In the same way whole hands of "female" flowers towards the distal end of the bunch may fail to produce ovaries greater than one-tenth the size required for marketable fruit. The failure is particularly noticeable in bunches which are extruded just following drought periods and with these it would seem that translocation may have been a factor.

DEVELOPMENT OF THE FRUIT.

The development of the fruit commences within the pseudostem and is thus concurrent with that of the later flowers. By the time the inflorescence emerges from the throat the proximal flowers may have the ovaries developed almost to the full length that they are to attain, though the filling of the ovary is not proportionately far advanced (Plate 22). As the development of the fruit is parthenocarpic and takes place to such an extent before the inflorescence appears it is difficult to define a point at which flower development ceases and that of the fruit commences. To a certain extent, then, the discussion on the development of the flower applies directly to the fruit, the degree of femaleness being within limits virtually synonymous with the property of fruitfulness.

Number of Fruit.

Generally speaking, though the number of fruit in each hand is by no means constant, even when the position of the hand in the bunch is taken into account, the greater the number of hands the greater will be the number of fruit in each of the hands. Though there are exceptions, which will be mentioned later, the number of fruit in each hand and the size to which the individual fruits develop decrease progressively towards the distal end of the bunch. One limiting factor in the yield has been discussed, therefore, in considering the hands of "female" flowers in the immediately preceding section.

If the characteristics of bunches appearing at various times are examined it is found that so far as number of fruit in the hands is concerned there is much evidence which suggests that the number is determined very early in the history of each hand. At certain times of the year, for example, bunches are found in which the first hand contains many fewer fruit than the subsequent ones. This is quite distinct from the failure of some "female" flowers to develop fruit, which has been mentioned earlier. In the cases now under consideration the fruit is well developed and there are no scars indicating that fruit has been differentiated but has aborted or fallen. The fruit which matures is obviously all that was ever present. In 1940 the feature of smaller numbers in basal hands was noted particularly in bunches which matured in the first week of

August or a little earlier and again in bunches which appeared in December. The former bunches would have been budded early in January whilst the latter would have commenced differentiation during July or August. The first three weeks of January of that year were particularly hot and dry. This period was finally broken by heavy rain amounting to almost 12 inches during the following three weeks. Similarly no effective rain fell between July 5 and August 19 of that year and after that time effective falls were again recorded. The climatic factors during the developmental periods of these two sets of bunches have very little else in common, the one commencing in the summer and progressing through the winter, whilst the other commenced towards the end of the cold season and was marked by gradually rising temperatures and longer days for a considerable period. It is concluded, therefore, that the number of "female" flowers is determined during the early stages of the development of each hand and that sudden changes are apt to occur.

Table 19.

Relationships of Number of Fruit, Ts and Index.

Ts.	I.	No. of Fruit.	Ts.	I.	No. of Fruit.	Ts.	I.	No. of Fruit.
1,933	1,542	85	2,360	2,826	139	2,117	2,964	153
1,951	1,307	69	1,518	1,366	93	1,928	2,506	136
1,642	1,806	117	1,605	1,283	57	2,450	3,601	123
1,846	2,089	115	1,764	1,940	122	2,226	3,339	120
1,962	1,706	79	1,942	1,942	136	1,994	2,592	121
1,793	1,741	75	1,724	1,896	133	2,358	3,372	138
1,982	2,379	141	1,989	2,586	153	2,052	2,524	144
1,792	1,774	79	1,553	1,553	99	2,059	3,232	139
1,781	1,786	144	2,179	2,755	147	2,108	3,141	153
1,984	2,375	138	2,168	3,171	157	2,077	3,054	131
1,894	2,033	109	1,477	1,326	84	2,244	3,388	163
1,816	2,052	137	2,325	2,906	158	2,023	2,832	119
1,970	2,364	128	2,476	2,971	143	1,840	2,447	110
1,784	1,605	91	1,847	2,457	128	2,134	3,137	151
1,920	2,112	103	2,160	2,938	136	1,919	2,552	131
1,988	2,386	122	1,863	2,347	115	1,961	2,608	131
2,098	2,727	143	1,933	2,707	127	1,989	2,586	138
1,845	2,326	110	2,090	3,135	164	1,815	2,196	120
1,932	2,705	146	1,983	2,385	125	1,721	2,012	107
1,722	2,325	131	1,651	2,262	124	1,892	2,460	135
1,564	1,877	103	1,706	2,096	91	1,479	2,041	95

The probable relationship between degree of femaleness developed in the flower and the period of activity of the meristem has already been traced. It appears now that on *the degree* of activity of that tissue depends the number of initials laid down in the first place. The degree of activity will depend on general growing conditions and thus, whilst the number of hands is dependent largely on external conditions modified by the age of the plant, the number of fruits in any one hand is bound up with internal and external factors. Hence external factors are of consequence in several ways in the determination of

number of fruit and it is at once apparent that the number of fruit may be so subject to climatic conditions that care must be exercised in using yield data as a basis for comparison between differential fertilizer treatments.

An examination of the average number of fruit in bunches thrown at different times of the year, as shown in Table 22 (page 97), indicates the possible extent to which climatic factors may enter into the determination of yield. When such examination is being made of the table it must be borne in mind that the most rapidly growing plants naturally bunched earliest. It is apparent, then, that the extra vigour which caused these plants to complete their development in the shorter period not only did not enable them to produce more fruit but the numbers were actually smaller in every grouping than in the case of plants which required as much as three months, or over 25 per cent., longer to reach the flowering stage.

The question may be examined from the point of view of food supply. The rate at which food can be made available for fruit development would depend, in the first place, on adequate amounts having been manufactured by the plant. There is sufficient evidence to allow Ts of these plants to be taken as a measure of the amount of material on which the plant may draw. Table 19 shows the number of fruit compared with Ts of the plant which bore them at the time at which the bunch appeared. An examination by statistical methods shows that there is a good correlation between the two. The relationship was examined by means of the following expressions, in which y is the number of fruit:—

$$\text{Regression equation, } y - 123{\cdot}1 = {\cdot}0651\ (\text{Ts} - 1933)$$

$$r = {\cdot}5993\ (61\ \text{D.F.}).$$

The correlation is found to be significant. Nevertheless both theoretical deduction and field observation strongly suggest that climatic factors are of decided importance. Climatic factors, of course, enter into the calculation of Ts but the immediate expression of these is to be found in the area of leaf produced at the particular time. The difference between the numbers of fruit produced by various individual plants is largely due to the extra hands above a certain minimum. Thus if a banana plant fruits at all it is very abnormal for the bunch to have less than four hands of fruit and in the case of the field trial plants the smallest number of hands borne was six. It seems logical, then, to look for the differences late in the development of the flowers. Accordingly, the area of the last three leaves was examined and it was found that in this, too, there was a very highly significant correlation with the number of fruit. Of course, the area of leaves and the Ts are not independent and it was decided to combine the two measurements. Accordingly an index was calculated by multiplying the Ts by the average area of the last three leaves of the plant. This index is given in Table 19 under the heading of I. It shows a very high correlation with the number of fruit, the regression equation being:—

$$y - 123{\cdot}1 = {\cdot}0326\ (\text{I} - 2388).$$

$$r = {\cdot}7623\ (61\ \text{D.F.}).$$

The correlation of the number of fruit with the index is higher than with the Ts and a test in which allowance was made for the correlation between Ts and Index showed that the difference was significant. This means that the index is a significantly better indicator of the number of fruit produced than is the Ts. The relationships of some external factors to the number of fruit produced may be examined by the use of partial correlations. With respect to temperature, for this purpose the mean temperature over the four weeks immediately preceding flowering was taken. Soil moisture offered greater difficulty and the method adopted was as follows:—the rainfall on each day was carefully plotted, and working from the field capacity the rate of drying was deduced theoretically. No true figure could be found in this respect and all that could be done was to use the knowledge gained over 12 years of experience with the type of soil. Very low soil moisture was given a value of 3 while maximum field capacity was rated at 15. Three intervening points were recognized corresponding to the qualitative classification of fair, medium, and high. The period over which soil moisture was considered coincided with that for temperature. The relevant data are shown in Table 20.

The following summarizes the analysis of variance:—

ANALYSIS OF VARIANCE—Number of Fruit.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Regression	3	33,885·4	11,295·13
Remainder	85	11,036·3	129·84
Within Plots	88	44,921·7	..

F for regression = 87·0, which is very highly significant.

The regression equation is:

$$y - 123{\cdot}29 = -7{\cdot}3059\ (x_1 - 72{\cdot}91) + 4{\cdot}4022\ (x_2 - 9{\cdot}22) + 1{\cdot}2446\ (x_3 - 380{\cdot}94),$$

where y = number of fruit, x_1 = temperature, x_2 = soil moisture, and x_3 = number of days to flowering. The s.e. and the "t" values are given below—

b_1 — 7·3059 — 1·0684 $t = 6{\cdot}838$.
b_2 4·4022 — 0·6199 $t = 7{\cdot}101$.
b_3 1·2446 — 0·1277 $t = 9{\cdot}746$.

b_1 shows the correlation with temperature when the soil moisture and period to flowering are constant; b_2 the correlation with soil moisture when temperature and period remain constant; and b_3 that with period when the other two factors are constant.

The values of t show that all the regression coefficients are very highly significant (P 1 x 10 $^{-9}$).

It is thus evident that the number of fruit is closely linked with the climatic conditions prevailing over the period of development of the last three or four leaves.

In view of the close connexion between Ts and the number of fruit, it is necessary to examine more closely the factors which have been combined to produce this measure. In the first place, time is of importance and other factors being equal the more rapidly the plant grows the smaller will be the Ts at bunching time. Thus a stimulation of growth may tend to reduce the number of fruit. Against this, however, there is the fact that the Ts must reach a certain figure before fruit buds can be initiated, so there is a limit to the reduction in yield that can be thus brought about. Of the other factors the climatic ones in themselves are outside control but this does not mean that nothing can be done towards altering their effect on the plant. The effect of climate on Ts depends to a large degree on the state of advancement of the plant when any particular set of conditions operates. Thus by varying the planting time the

Table 20.

Data Concerning Climatic Influences on Fruit Numbers.

BLOCK I.					BLOCK II.				
Treatment.	No. of Fruit.	Temp. °F.	Soil Moisture. %	Period to Flowering.	Treatment.	No. of Fruit.	Temp. °F.	Soil Moisture. %	Period to Flowering.
O	125	75	9	411	O	138	75	9	411
	109	77	9	418		122	72	12	362
	151	73	12	369		68	67	6	327
N	107	77	9	415		96	67	6	327
	110	74	12	404	N	84	68	6	341
	111	74	12	404		131	80	12	425
	114	77	9	418		98	70	6	348
P	136	72	12	362		96	66	6	327
	139	77	9	418	P	123	75	9	411
	143	74	15	397		138	77	9	418
	134	73	9	390		131	76	9	414
K	143	75	9	411		153	80	12	425
	120	75	9	418	K	138	69	9	355
	105	74	12	404		141	69	9	355
	88	68	3	334		106	67	6	327
NP	146	80	12	425		162	69	9	355
	158	73	12	369	NP	143	80	12	425
	123	77	9	418		131	75	9	411
	125	68	6	341		160	80	12	425
NK	153	73	12	369		145	75	9	411
	91	68	3	334	NK	57	67	6	327
	119	67	6	327		133	72	12	362
	108	68	6	341		51	69	9	355
PK	157	74	9	390		139	73	12	369
	128	68	9	343	PK	164	80	12	425
	170	73	12	369		119	80	12	425
	92	68	3	334		180	75	15	397
NPK	110	75	9	411		138	75	9	411
	124	80	12	425	NPK	141	74	12	404
	108	80	12	425		79	68	3	334
	118	73	9	383		..	75	9	411
						163	72	12	362

Table 20—continued.

DATA CONCERNING CLIMATIC INFLUENCES ON FRUIT NUMBERS.

BLOCK III.					BLOCK IV.				
Treatment.	No. of Fruit.	Temp. °F.	Soil Moisture. %	Period to Flowering.	Treatment.	No. of Fruit.	Temp. °F.	Soil Moisture. %	Period to Flowering.
O	128	73	9	383	O	136	74	12	397
	137	69	9	355		111	74	12	404
	133	73	9	383		119	74	12	404
N	85	67	6	327	N	120	74	12	397
	93	70	6	348		131	77	9	418
	67	68	3	310		153	75	9	411
	50	67	6	327		131	77	9	418
P	69	67	6	327	P	131	77	9	418
	79	68	6	341		153	80	12	425
	80	68	6	341		134	80	12	425
	126	72	12	362	K	121	75	9	411
K	119	68	6	341		155	73	9	383
	117	68	6	341		121	75	9	411
	162	73	12	369	NP	125	75	9	411
	82	67	6	327		115	74	9	397
NP	151	75	9	411		111	78	15	445
	73	68	3	334		128	80	12	425
	146	68	6	341	NK	153	77	9	418
NK	115	70	6	348		147	73	9	390
	99	70	6	348		130	74	12	404
	72	68	6	341		140	74	12	404
PK	99	69	9	355	PK	153	74	12	404
	139	73	12	369		103	70	6	348
	143	77	9	418		134	70	6	348
	126	74	9	397		138	69	9	355
NPK	144	74	12	404	NPK	163	80	12	425
	109	68	6	341		122	69	9	355
	165	74	12	404		153	73	12	376
	132	72	12	362		131	74	9	383

lowering effect due to stimulation of growth may be offset to a certain extent. A limit to the offsetting is caused by the fact that if large proportions of the leaves are thus brought under the most propitious conditions a reduction in the time will automatically follow. The plants in the field trial were planted in December, with the result that the most vigorous budded in April and May and flowered in October and November. Because of the rather poor growing conditions at the time the bunches carried but small numbers of fruit. Had these plants been set say three months later and grown at the same general rate they would have flowered three or possibly four months later and would thus have been subject to good conditions at the most important period. These good conditions were experienced, however, by the more backward plants. There are other factors which must be considered, notably that the number of hands will almost certainly be smaller in the case of quickly developing plants; but if a long range view is taken it will be seen that the stimulation of growth, even

were it to lead to a slight reduction in the size of any one crop, must ultimately be of benefit by increasing the number of crops which can be produced over a number of years.

The position then with respect to the number of fruit is that, as the index is a significantly better indicator of production than is Ts, it is necessary to consider not only what the plant has done but more particularly what it is capable of doing during the time of fruit development. The latter depends so much on the climatic conditions that it is apparent that yield alone cannot be taken as a valid index of the nutrition of the plant, and the results of fertilizer experiments based solely on yield cannot be exepected to provide reliable data unless at the same time due consideration is given to the climatic factors by the use of appropriate statistical methods.

If yield data are to be used for the purpose of assessing nutritional effects it is necessary to carry the experiments over a number of years to obtain sufficient data on climate. Further, with the banana there is a general tendency for crops to become progressively lighter, and though this may be due partly to lowering of the soil fertility it would be necessary to assess to what extent the plant itself enters into the question. To take crops at their face value and directly compare the first and say fourth crops merely because they were borne under similar climatic conditions is open to several objections.

Influence of Following Sucker.—After the plant has budded there is one condition which is probably different for all plants, namely, the size and development of the sucker which is being allowed to grow as the follower. As this sucker arises from and remains attached to the parent corm it seems possible that differences between the efficiencies of various plants in the matter of fruit production may be brought about to some extent by any drain on available nutrients or reserves which may be imposed by this sucker. Observation, however, suggests that the sucker quickly produces sufficient roots to maintain itself. If comparisons are to be made between plants it is, of course, necessary to take climatic conditions into account and thus the only plants which can be compared directly are those flowering at the same time. However, the index (I) used earlier as an indicator of potentiality of crop size takes climate into account and therefore can be used. Although this index and the number of fruit are very highly correlated divergences occur and the relation of those divergences to the age of the sucker may be examined. Table 21 shows the figures obtained for 20 plants. The differences in apparent age of suckers at time of flowering are not great, because the growth of the parent was given some consideration in the choice of time for allowing the sucker to grow in the first place. There is no suggestion that the age of the sucker has had any effect. Taking the plants tabulated from 28B to 14A it will be seen that the ages of the suckers, i.e., the length of time they have been producing leaves, show differences of up to 68 days but that the index divided by the number of fruit is the same for all plants. Similarly plants 20A to 1B show uniformity in one respect and marked divergence in the other. With these plants, then, the drain of the sucker on the parent, if proportional to the age, is of no moment so far

Table 21.

Relation of Apparent Age of Sucker to Number of Fruit.

Plant No.	I/No. of Fruit.	Appt. Age of Sucker.	Plant No.	I/No. of Fruit.	Appt. Age of Sucker.
		Days.			Days.
15A	24	53	19A	19	36
28B	23	26	17B	19	— 4
24B	23	26	13A	19	50
10B	23	43	29B	19	50
6B	23	47	2A	19	63
14A	23	—21	20A	18	36
19B	22	—15	4B	18	—31
25B	21	10	3B	18	— 7
22B	20	13	13B	18	40
16A	19	56	1B	18	23

as efficiency in fruit production is concerned. The apparent age is subject to the qualification mentioned earlier in connexion with relative increase in the leaf area in that the sucker may have been partially removed earlier and have grown again.

Influence of Ts.—The relatively small variation in the number of fruit borne by different plants which flower at the same time of the year could be attributed to genetical differences, microenvironment, or some factor connected with the history up to fruiting time. Genetical differences appear to have been very small if the deduction from the results of the application of the efficiency in growth formula is correct. Similarly effects due to differences in micro-environment should be reduced to a minimum by the replication of plots used; and it thus becomes necessary to consider other effects, such as may be connected with or measured by Ts.

Budding takes place when the product of Ts and the area of leaf produced tends to a fixed point ($56{,}000 \times 10^7$). It follows, then, that in extreme cases one or other of these factors must be very large, comparatively speaking. If budding takes place when the product of area produced and Ts is 56, theoretically any two factors of 56 will be effective. Thus if the Ts is 56 a leaf area of 1 will suffice and if the Ts is 1 the leaf area will have to reach 56. The established correlations show that if the Ts is 56 the plant is able to produce correspondingly large areas when subject to good growing conditions. This means that in any event the plant which buds must be capable of producing large leaves under propitious conditions. If it is able to produce large leaves it is evidently capable also of producing large bunches. Thus, whilst the Ts is of particular importance in determining the initiation of the sex phase, the climate becomes the important component from then onwards. As the factors dependent on climate do not undergo sudden violent changes, except perhaps at the breaking of a drought, the potential of the Ts of all plants budding at the same time must be approximately the same, the maximum difference being proportional to the variation in climate over the short period between the laying down of successive leaves. Thus differences in numbers due to differences in

Ts can occur but they can rarely be very large. Larger differences can be brought about by the variation in the number of immature leaves to be developed after budding, as has been pointed out. It is this difference that accounts for the small bunches frequently found on the very rapidly growing, luscious types of plants at times when more normal plants are producing large bunches.

In effect, this means that if two treatments are such as to cause the plants receiving them to flower at the same time there will be probably little to choose between them so far as the number of fruit produced is concerned. If this is so it means that *the size of a crop in respect to number of fruit can be influenced only by the time of the year at which it is borne and cannot be increased merely by the use of fertilizer; and, further, unless planting times are carefully arranged reduction in crop may result from the addition of a food material in which the soil is actually deficient.*

The only way in which the treatment could directly influence the size of the crop would be by affecting fruit development in some way not manifested in the vegetative growth of the plant. It is difficult to visualize this taking place when the development of the fruit is wholly parthenocarpic. The number of bunches thrown at any one time by the field trial plants renders it impossible to reach any valid conclusion on the point. Again, over a period of years use could be made of partial correlations, but in this work only seven temperature points would be available. An inspection of temperature records over the previous few years was made and it seems that even if the whole period of usefulness of most banana plantations were to be used the number of temperature points would still be rather small; for there is surprisingly little variation in the mean temperatures for any one month as between one year and the next. In Table 22 is given the average number of fruit per bunch produced under

Table 22.

AVERAGE NUMBER OF FRUIT PER BUNCH.

Date.	TREATMENT.								
	0	N	P	K	NP	NK	PK	NPK	Means.
Oct. 10–31	82	67	103	92	73	81	92	79	81
Nov. 1–14	..	79	80	118	107	102	148	109	106
Nov. 15–30.. ..	130	93	131	147	..	133	138	139	130
Dec. 1–14	151	..	..	162	158	146	155	173	158
Dec. 15–31 ..	131	..	134	155	..	147	157	151	146
Jan. 1–14	126	116	143	105	137	135	153	148	133
Jan. 15–31 ..	109	127	139	127	136	153	142	163	137
Means	122	96	122	129	122	128	141	137	..

each of the eight treatments used in the field trial. Differences will be observed but they can be taken only as indicative. That is to say, in the absence of further information it would appear that chance has played too big a part to permit of sound information being obtained. Although nitrogen alone has produced

a distinctly lower average than any other treatment it must be noted that the plants which received only this material produced no bunches during December, at which time other plants were producing their largest bunches.

Fruit Filling and Maturation.

The periods taken for the fruit subjected to the different treatments to develop from the date of flowering to harvesting time are given in Table 23.

Table 23.

PERIOD FROM FLOWERING TO FRUIT MATURITY.

Plant No.	Treatment.	Flowering Date.	No. of Days.	Plant No.	Treatment.	Flowering Date.	No. of Days.
1A	O	16–1–40	126	17A	NPK	11–1–40	131
1B		23–1–40	133	17B		10–11–39	115
1D		5–12–39	110	17C		9–1–40	118
2A	NP	30–1–40	126	17D		28–10–39	119
2B		5–12–39	125	18A	K	7–11–39	118
2C		23–1–40	119	18B		7–11–39	133
2D		7–11–39	111	18C		5–12–39	110
3A	NK	29–11–39	132	18D		24–10–39	96
3B		31–10–39	105	19A	P	24–10–39	124
3C		24–10–39	96	19B		7–11–39	98
3D		7–11–39	128	19C		7–11–39	98
4A	PK	23–12–39	107	19D		28–10–39	112
4B		7–11–39	138	20A	N	24–10–39	112
4C		5–12–39	110	20B		14–10–39	104
4D		31–10–39	89	20C		7–10–39	142
5A	NPK	14–1–40	113	20D		24–10–39	112
5B		30–1–40	126	21A	NK	5–3–40	175
5C		30–1–40	126	21B		19–11–39	102
5D		19–12–39	111	21C		14–11–39	104
6A	N	20–1–40	107	21D		7–11–39	98
6B		9–1–40	105	22A	PK	21–11–39	124
6C		9–1–40	133	22B		5–12–39	110
6D		23–1–40	119	22D		21–1–40	112
7A	P	28–11–39	118	23A	O	16–12–39	114
7B		20–1–40	122	23B		21–11–39	139
7C		2–1–40	111	23D		19–12–39	111
7D		26–12–39	118	24A	NP	15–1–40	112
8A	K	11–1–40	116	24B		31–10–39	105
8B		15–1–40	127	24C		7–11–39	95
8C		9–1–40	118	24D		9–1–40	118
8D		31–10–39	89	25A	PK	9–1–40	118
9A	P	19–1–40	123	25B		14–11–39	126
9B		20–1–40	136	25C		14–11–39	126
9C		16–1–40	111	25D		28–11–39	124
9D		30–1–40	126	26A	NK	25–1–40	131
10A	NPK	9–1–40	118	26B		23–12–39	122
10B		31–10–39	118	26C		9–1–40	105
10C		16–1–40	..	26D		9–1–40	105
10D		28–11–39	116	27A	NP	19–1–40	123

Table 23—continued.

PERIOD FROM FLOWERING TO FRUIT MATURITY.

Plant No.	Treatment.	Flowering Date.	No. of Days.	Plant No.	Treatment.	Flowering Date.	No. of Days.
11A	K	13–11–39	132	27B		2–1–40	125
11B		16–11–39	129	27C		20–2–40	..
11C		24–10–39	96	28A	O	2–1–40	125
11B		21–11–39	124	28C		9–1–40	133
12A	N	7–11–39	119	28D		9–1–40	118
12B		30–1–40	126	29A	NPK	28–1–40	145
12C		14–11–39	104	29B		21–11–39	139
12D		24–10–39	96	29C		12–12–39	118
13A	NP	30–1–40	126	29D		19–12–39	111
13B		17–1–40	125	30A	N	3–1–40	123
13C		10–1–40	126	30B		20–1–40	136
13D		16–1–40	126	30C		16–1–40	140
14A	NK	24–10–39	96	30D		23–1–40	133
14B		28–11–39	117	31A	P	20–1–40	136
14C		21–11–39	97	31B		5–3–40	175
14D		5–12–39	97	31C		30–1–40	126
15A	O	13–1–40	114	31D		30–1–40	126
15B		28–11–39	117	32A	K	27–2–40	182
15C		24–10–39	96	32B		17–1–40	110
15D		24–10–39	96	32C		19–12–39	111
16A	PK	30–1–40	126	32D		16–1–40	111
16B		30–1–40	112	..	..	..	..
16D		16–1–40	111	..	..	..	..

The term "maturation" is not strictly applicable, for bananas are not allowed to ripen in the plantation but are cut when they are considered to have attained full size and will be in the best condition for consumption by the time they reach the consumer. Thus cutting time depends to some extent on the market to which they are to be sent and on the time of the year at which harvesting takes place. The period is then not very satisfactory unless, as was unfortunately not the case in this investigation, full control of the cutting time is assumed by one man acting solely on some quantitative measure and independent of any market requirements. However, the figures tabulated may be taken as approximately accurate for maturation periods, for only one man's judgement was used. From these figures it will be seen that there is little difference between treatments in respect to the maturation period and it seems clear that its duration is controlled by climatic conditions and not by nutrition. For example, bunches appearing towards the end of October are ready for cutting in about three months whilst those appearing in February take more than a month longer, no doubt owing largely to the falling off in temperature at this period of the year.

The shortest period required was that by plant 4D which was ready for cutting 89 days after it had flowered at the end of October, whilst plant 32A which flowered at the end of February occupied 182 days in the process. Both of these plants received dressings of potash, which is the only material associated

with beneficial results in vegetative growth. *A general survey of the figures shows that there is little material difference between plants which flowered at the same time of the year and certainly none that could be ascribed to any nutritional differences brought about by the fertilizer treatments.*

Table 24.

Average Weight of One Fruit in Ounces.

Date of Flowering.	Treatment.								Means.
	0	N	P	K	NP	NK	PK	NPK	
Oct. 15–31 ..	3·8	4·4	4·0	3·8	4·0	3·8	3·0	4·4	4·3
Nov. 1–10	..	2·2	4·3	4·5	4·0	4·3	3·0	4·5	4·0
Nov. 11–20.. ..	..	3·5	..	..	..	4·5	4·4	..	4·3
Nov. 21–30.. ..	2·7	..	3·6	4·2	4·3	..	4·3	4·1	4·0
Dec. 1–10	2·9	..	..	2·2	3·3	4·0	3·6	..	3·4
Dec. 11–20 ..	3·7	..	..	3·9	..	..	..	3·6	3·7
Dec. 21–31 ..	..	..	..	..	..	3·7	4·3	..	4·0
Jan. 1–10	3·8	3·6	3·9	4·3	3·6	3·6	3·3	3·9	3·7
Jan. 11–20 ..	3·9	3·6	4·0	3·8	2·9	..	3·8	4·1	3·2
Jan. 21–31 ..	3·5	3·3	3·0	3·8	3·1	3·4	3·0	3·1	3·2
Means	3·6	3·5	3·7	3·9	3·9	3·9	3·7	3·8	..

The size of the fruit is an important consideration; but, as can be seen from the data tabulated in Table 24, the variation within treatments is as great as that between treatments and in the absence of a large number of comparable bunches definite information on the effects of fertilizer treatments cannot be given. General observations on the field trial plots and on other plantations suggest that, in the matter of size of fruit, climatic influences again play an important part; and fruit maturing through the winter or subjected to long dry periods is generally found to lack the size of that filling under higher temperatures or in periods during which the general growing conditions are good. Bowman and Eastwood (1940) reported a probable increase in size of fruit following the use of potash. This was the only benefit ascribed to this material by these authors, who apparently based their results wholly on yields.

There is some indication from the figures given in Table 24 that potash has increased the average weight, but again nothing conclusive can be stated. It must be remembered that an increase of one-third of an ounce per fruit would make a difference of perhaps half a ton of fruit over an acre. Owing to the small number of comparable bunches the matter cannot be pursued further, although there seems little reason to doubt that weight of fruit is very largely a nutritional effect; but until the modifying influence of climate is determined it appears unwise to make direct comparison between bunches not maturing through the same period.

SECTION 5.

EXAMINATION OF QUANTITATIVE RESULTS.

General.

From what has been recorded it is clear that in any analysis of data concerning the nutrition of the plant it is essential that due consideration be given to the basic facts of the development of the plant. The outstanding points which must be kept in mind may now be summarized as follows:—

1. The relative growth rate of the plant, as measured by the percentage increase in the leaf area, is controlled for a large part of the plant's life by factors not attributable to differences in nutrition; and a measure of leaf area is apt to give misleading results concerning nutritional effects if taken over any period extending much beyond the time of completion of the first sub-stage of Stage 1 of the development.

2. The time required for the plant to produce its first flower bud gives a reliable guide to its rate of development, whereas the time required for the production of the flower does not. This is so because, whilst the ability of the plant to bud is largely dependent on the rate at which the leaf area has been produced, the interval between budding and flowering is determined essentially by the number of leaves which have still to be developed. As temperature and soil moisture, perhaps acting in combination with other external factors or indirectly, constitute the limiting influences so far as time taken to produce leaves is concerned, it is obvious that when this second stage in the development of the plant is included in the period the effect of mineral nutrients may not be truly measured. When, as in this investigation, the most forward plants develop the final leaves through the winter and the backward experience the more favourable summer temperatures a levelling must result. If the seasons were reversed the opposite effect would be caused, so that in any event an error is introduced and the period from planting to flowering cannot be taken as a valid index of rate of development.

3. The value of the total area of leaf produced as a measure of plant growth is reduced by a number of factors. The position may be considered from the point of view of development. Whilst budding is not to be considered merely as a direct result of growth the amount of growth is nevertheless a dominating factor and the amount of leaf produced is governed by both internal and external factors. Thus once a plant has budded its ability to take advantage of enhanced growing conditions is limited by the number of leaves it has yet to develop to maturity. The size of the leaf cannot by that time be increased by the addition of mineral nutrients to the soil. The size of the leaf is limited, apart from environmental influences, by the previous history of the plant, so normally there can be no sudden increase or decrease in the size of the leaf produced. The condition of normality is introduced, for it is conceivable that irrigation or the sudden breaking of a prolonged drought may have

beneficial effects of a high order. Drought, on the other hand, is necessarily a slow and gradual influence and would not have the opposite effect. The relationship between Ts and the area of leaf produced at budding time is a simple arithmetical one. If, then, a plant buds at a low Ts it can do so only if it has ability to produce a relatively large leaf, and as the weather generally changes but gradually the remaining leaves would also tend to be of large size. The reverse holds true also, so the tendency is for all plants to produce total areas of the same order. The differences which do occur seem to be brought about largely by the variation in the number of leaves to be completed after floral parts are initiated. Thus the older a plant is when budding takes place the larger the total area will tend to be, subject always to the influence of climatic factors. As the number of leaves which have to be developed during Stage 2 of the development of the plant seems to be a function of age of plant, and not directly attributable to nutrition, it appears that there is little to be gained from a consideration of the total areas of leaf produced. The position may be made clearer by considering two examples. Plant 12A produced 17,345 square inches of leaf surface, whilst 15A finally totalled 28,120 square inches, these being respectively the lowest and highest totals attained by the plants under investigation. Plant 12A is calculated to have had but eight immature leaves within the pseudostem at budding time, whilst 15A had 11 comparable leaves. The last three leaves of 15A added 4,457 square inches, or a little less than half the difference between the two plants. In the absence of any evidence that the number of immature leaves present at the end of Stage 1 is a nutritional effect, it can only be concluded that the total area produced cannot be regarded as a measure of differences between treatments, although its production cannot be wholly dissociated from nutrition.

The method whereby the Ts of the plants is calculated is such that valid direct comparisons using this factor can be made only if the climatic conditions remain constant for all plants. In these circumstances the Ts cannot yield any more information than do the area of leaf and the longevity of the leaves.

Bearing the salient points of the development of the plant in mind, the quantitative results of the field trial can now be examined.

Rate and Amount of Growth.

The rate of growth may be measured by the leaf area produced over a known period; and comparisons can be made between plants simply by using the total areas produced, provided that the same external conditions have been experienced and the plants have all been in the same stages of development. The longest such period in the case of the field trial plants is from the date of planting to the time of completion of Stage 2 by the most forward plant. Up to that time all plants have experienced the same climatic conditions and have been in a position to take advantage of them. Appendix 4 is an analysis of variance of the figures obtained for the areas produced by the plants up to October 31, the approximate date of completion of Stage 2 by the earliest maturing plants. It shows that a significant increase in area has occurred in the

presence of potash but not in any other case. The following summarizes the position, each figure representing one-hundredth of the mean leaf area in square inches per two plants:—

	K_0	K_1	s.e.
Mean	297·4	334·9	12·02

	0	N	P	NP	K	NK	PK	NPK	s.e.
Mean ..	307	301	324	296	354	363	340	320	24·05

The limitations of the final total area produced have been discussed and it is of interest to note that, though rates of production and amounts vary significantly over specific periods, an analysis of variance of total areas shows no such significant differences (Appendix 10). There is considerable variation in the number of leaves produced by different individuals, the maximum obtained in the field trial being 51 and the minimum 31. It has been noted that there is but small variation in the proportion of the area added after budding though the time occupied in its production may vary greatly. For example, plants 3B and 31B added 42 per cent. and 47 per cent. respectively of their total areas after the calculated time of budding; but, whilst 3B required 149 days, 31B accomplished the increase in 79 days. As so great a proportion is added during a period when the nutritional effects are subject to uneven modification by climatic conditions, it is not surprising that differences, which have previously been found statistically significant and which were apparent to the eye, disappear.

Ts of Plants.

For reasons which have already been given the use of Ts as a measure of nutritional differences is not considered sound, in as much as time is an important factor and the climatic influences at work are not the same for all plants after the first plant completes Stage 2. In Figure 25 is shown the Ts at bunching time for each of the field trial plants. This diagram suggests that there is some correlation between Ts and the climatic conditions towards the end of the growing period; and this might be expected, since at that time the greatest area on the plant is operating. An analysis of variance (Appendix 5) does not suggest that the differences in Ts are in any way associated with manurial treatments.

Rate of Development.

The variations between plants are essentially in respect to rate of development, this being due mainly to the fact that the banana does not fruit at any specific time of the year, as do many plants, but after a period to be measured solely in terms of the history of the plant. As the development is divided naturally into stages it is necessary to examine the data for each of these periods separately, at least in the first instance.

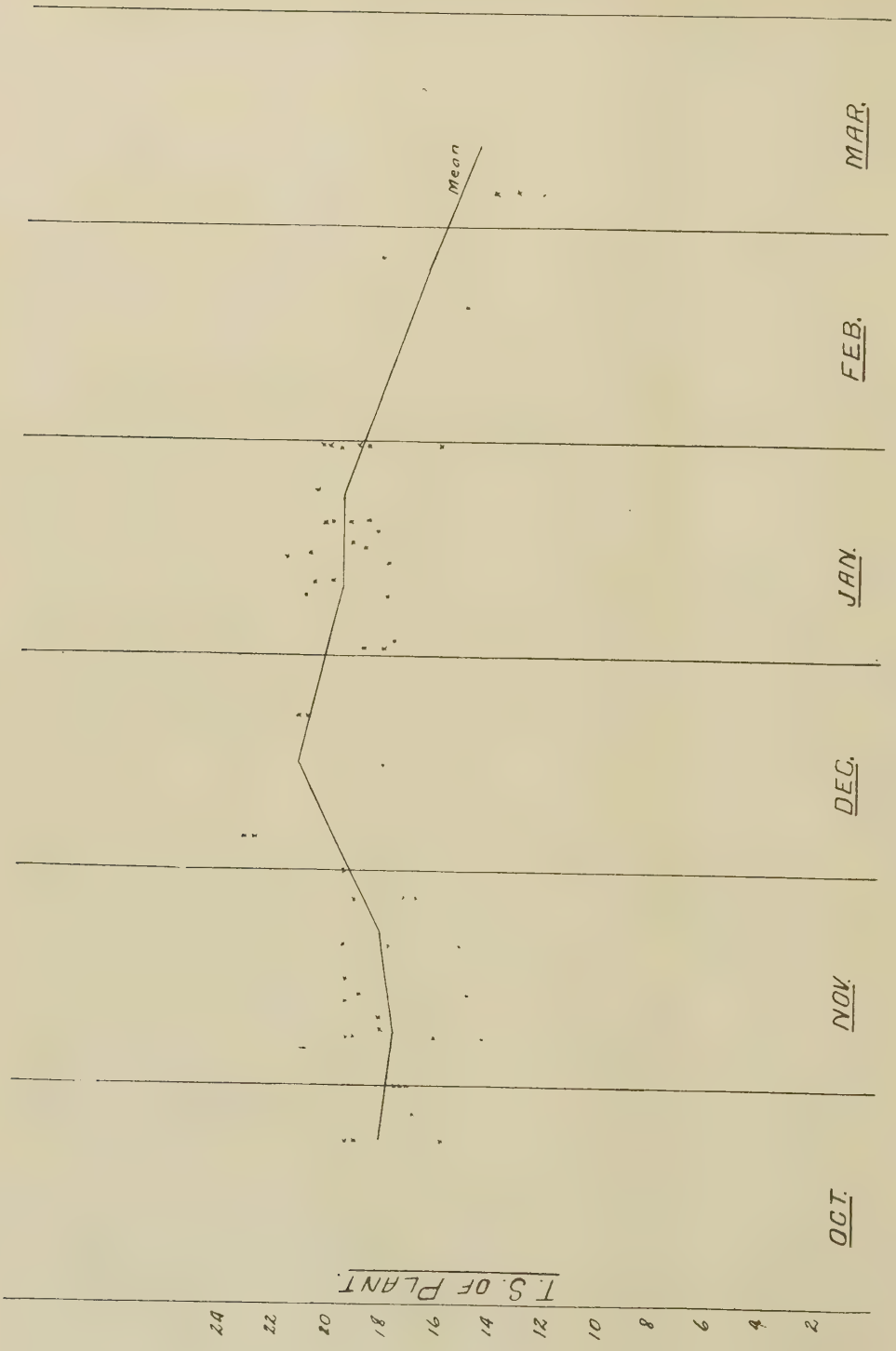


FIG. 25.—Showing Ts. of Plants at Time of Flowering.

The rate of development during the first stage may be assessed in terms of the periods required by each plant to complete this stage. In Appendix 6 is given an analysis of variance of the figures used, which were calculated as described above and are set out in Table 20 (pages 93 and 94). Doubt is cast on the validity of the result owing to the high sampling error. If the result stood alone and not supported by observation it could be accepted only as an indication; but as the rate of development to this stage is so closely bound up with rate and amount of leaf growth it seems correct to conclude that the difference is in fact significant. It must be remembered that the end point of the stage is not determined directly and there are known sources of error. A summary of the figures is given below.

Mean Periods (in Days) for Completion of Stage 1.

	P_0	P_1	K_0	K_1	Means.
N_0	248	232	255	225	240
N_1	230	248	261	226	243

	K_0	K_1
P_0	260	218
P_1	262	234

The analysis shows that a significant reduction in the number of days required for the plant to reach the stage of flower bud initiation is associated with the addition of potash.

If use is made of the period to flowering it is essential to bear in mind that this is the sum of two stages, one of which is only indirectly connected with nutrition. The view may be taken that the number of leaves which have to be developed after bud initiation commences is not independent of nutrition since this leaf number is dependent at least to some extent on the rate of development. The difficulty might be overcome by computing how long the leaves would have taken to mature had all the plants budded on the same date; or, in other words, by giving each leaf a sliding scale value in days. This artificial calculation is simple, but there are many points which make its validity questionable at least; and as it has not been used it need not be discussed further. An analysis of variance (Appendix 7) shows that whilst none of the main effects is significant the decrease in period to flowering is approaching the necessary difference where potash was present. With respect to the interactions there is a definite suggestion that in the presence of phosphate there is a reduction in the time where nitrogen was applied, and that potash is associated with a reduction when nitrogen was present and also when phosphate was absent.

Growth and Development.

Growth and development have so far been treated separately in the consideration of quantitative results, but an examination of the two in combination is of value. In Table 25 is shown the mean daily area produced by each of

the plants during Stage 1. An analysis of variance of these figures (Appendix 8) shows that, in this respect again, plants which received potash showed a significantly greater daily production than those not so treated.

During the second stage of development environment exercises so great an influence on the period required for completion, through its effects on leaf production, that any true measure of differential nutritional effects is unlikely to be obtained.

The figures for the total of Stages 1 and 2 (Table 25) are, however, rather interesting. It will be seen that the differences between plants for the whole of their growing periods are very much smaller than during Stage 1. For apparently normal plants, i.e., plants not affected by outside agencies such as borers, the variation during the first stage is from 85 to 31 square inches per day, whilst for the combined periods of Stages 1 and 2 the maximum daily average is 69 square inches and the minimum 54 square inches. This is consistent with the results obtained by the use of the efficiency index and also with the observation that the plants tend to produce total areas of the same order.

Table 25.

Mean Daily Production of Leaf Area in Square Inches.

Plant No.	Stage 1.	Stages 1 and 2.	Plant No.	Stage 1.	Stages 1 and 2.
20A ..	83	66	27B	45	60
19A ..	80	64	25A	48	67
18B ..	71	64	28A	45	61
21B ..	69	64	9A	46	67
19B ..	74	62	8B	42	64
24B ..	72	63	32B	46	63
11B ..	67	65	15A	47	69
10B ..	69	63	17A	44	60
18A ..	72	62	7B	40	63
11A ..	66	65	26A	39	65
17B ..	68	64	30B	41	62
23B ..	63	61	29A	29	64
4B ..	72	68	16B	38	60
3B ..	68	62	5A	39	58
25B ..	70	63	24A	40	65
29B ..	72	68	31A	41	61
22B ..	60	60	12B	38	58
20B ..	55	50	13A	37	64
14A ..	68	59	1A	39	62
15B ..	63	58	9B	39	61
7A ..	60	59	6B	40	54
14B ..	59	57	16A	39	65
3A ..	62	64	30A	41	58
22A ..	57	54	2A	35	60
26B ..	53	62	27A	41	59
4A ..	57	68	6A	38	54
12A ..	54	51	13B	37	59
2B ..	55	60	5B	31	55
8A ..	50	65	23A	46	59
10A ..	45	64			

As might be expected, an analysis of variance of the rates of leaf production over the longer period fails to suggest that any difference is attributable to the treatments, though the length of the first stage has the effect of giving to those plants treated with potash values which approach significance (Appendix 9).

In the summary which is given below the rates of production of leaf area are shown as the sum of the two plants in each plot. The analysis gave an F value for K, 5·39, which is significant; the s.e. per plot was 17·9 = 17·1 per cent. of G.M.

Summary.

Mean Daily Production of Area in Square Inches prior to Budding.

	P_0	P_1	K_0	K_1	Means.
N_0	105·9	107·8	101·0	112·6	106·8
N_1	109·6	96·1	94·0	111·8	102·9
Means	107·8	101·9	97·5	112·2	104·8

	K_0	K_1
P_0	97·1	118·4
P_1	97·9	106·0

In the analysis for the combined periods of Stages 1 and 2 there were no significant values of F.

Summary.

Mean Rates of Growth—Stages 1 and 2 Combined.

	P_0	P_1	K_0	K_1	Means.
N_0	60·6	62·8	60·3	63·1	61·7
N_1	58·3	61·5	58·9	60·9	59·9
Means	59·4	62·1	59·6	62·0	60·8

	K_0	K_1
P_0	57·5	61·4
P_1	61·6	62·6

From all these data, then, it is apparent that when the plants have been in comparable stages of development potash has been associated with more rapid growth. Unless, however, cognizance is taken of the development the quantitative assessment of results is apt to give misleading information, for the total growth results in a definite levelling of effects.

SPECIAL CONSIDERATION OF NITROGEN.

Before drawing final conclusions from the investigation some consideration must be given to certain aspects of nitrogen metabolism within the plant. Many of the points are well known and are mentioned here simply to emphasize certain aspects.

It has been shown that the uptake of certain mineral nutrients is associated with the development of the meristem; and also how, from the time of completion of this stage of growth, further supplies of these nutrients produced no measurable effects on the plant though significant differences in the production of leaf areas were produced in the early stages of growth.

From the completion of the initial sub-stage growth proceeded at much the same relative rate in all plants. However, this relative increase varied considerably at different seasons of the year and general considerations showed that climatic influences were of importance in determining the rate. That climate exercises such a profound influence is not necessarily due solely to the direct effect on the components of the plant itself. As has already been mentioned climate is of moment also in determining the direction and extent of fluctuations of available nitrogen in the soil.

Nitrogen is required by the plants continuously for the further elaboration of carbohydrates to protein and other complex products of the plant. Certain of the mineral nutrients are also required in the metabolic process; but the quantity of nitrogen, like that of carbon, oxygen, and hydrogen, is relatively very large and though there may be accumulation of products such as proteins, which possibly provides reserves of nitrogen for the growing plant, nitrogen is continuously entering the plant and being assimilated more or less as it enters. As has been pointed out earlier, the rate at which the plant may utilize nitrogen for the production of new tissues is limited by the amount of other nutrients. The converse also holds true and it appears that the changes in growth rates may be due in part to the availability of nitrogen at the particular time. Thus an investigation of the effect of nitrogen-containing fertilizers may be subject to considerations not applicable to potassic or phosphatic manures.

The availability of all nutrients is not simply a question of their presence in or absence from the soil, but in the case of nitrogen the status of the soil is very readily changed. The absence of response to sulphate of ammonia at any stage of this investigation may mean either that there was always sufficient nitrogen available in the soil in comparison with other elements or that the plants were unable to obtain enough nitrogen to effect a change. Such inability could be brought about by a number of conditions, and particularly by a lack of soil organic matter.

SECTION 6.

CONCLUSIONS.

Whilst it is recognized that correlations in themselves cannot be assumed to prove any particular point, where sound botanical interpretations can be placed on the data they form very valuable, and in some cases probably the only practicable, evidence of physiological phenomena. Where, then, the botanical interpretations have appeared to be sound, deductions have been made from established correlations; and from these, the data, and repeated observations in the field, the following conclusions have been drawn:—

1. The production of each leaf is to a great extent independent of nutrition, provided this is adequate to support the normal life of the plant, and is governed largely by external factors. Of these external factors temperature, probably with soil moisture imposing limiting effects, is of outstanding importance. The rate of development of unit leaves is of moment not only in itself in direct obvious ways but also so far as it affects the time of development of the flower and the number of hands of fruit.

2. The established plant passes through three stages of development. The first of these is concerned wholly with vegetative increase and is divided into two sub-stages. During the first of these sub-stages the apical meristem is developed, and on the size of the organization then laid down the future of the plant fundamentally depends. This sub-stage is of short duration: in the case of the experimental plants it appeared to be completed within three months. The end point of this sub-stage, it is deduced, coincides with the production of an area of leaf rather than with a period of time; so if plants are set in a very dry period, for example, their future is not necessarily adversely affected.

3. Though the absolute potential of the meristems of individual plants may be widely different, the efficiency of meristematic activity over the vegetative stages of growth is the same for all. This uniformity, it is concluded, is conferred by the genetical constitution of the plant and is so maintained owing to the asexual method of propagation.

4. The amount of the meristematic tissue is the limiting factor in subsequent growth rather than the rate at which it is laid down. The rate of its development enters into the question, for the formative sub-stage is of limited duration and if the rate is low the size is automatically small.

5. The amount of these meristematic tissues is dependent on the supply of nutrients which the plant receives during this period and it appears that it is on the uptake of certain mineral nutrients, notably potash, that the plant's future ability to make use of nutrients in the production of new tissue depends. There is no conclusive proof that the total uptake of such minerals occurs in this period, but from all the evidence this must be considered a distinct possibility. It should, perhaps, be pointed out that in the banana a single apical meristem is being dealt with throughout life.

6. The second sub-stage is entirely vegetative and the rate at which it is completed is dependent on the effect of environment on the initial meristematic tissues.

7. The end point of the first stage is reached when differentiation of the sex organs is commenced, and Stage 2 which follows is characterized by the concurrent development of both sex and vegetative parts. Though the stimulus to growth is different these two are essentially vegetative parts, so that in this respect there has been no very drastic change and the measurement of total growth is not thereby made greatly different from formerly. From the beginning of this stage onwards no new foliage leaves are initiated, but those which have already been differentiated to an appreciable degree are developed as foliage leaves whilst those less advanced subsequently appear as bracts subtending either the inflorescence or the proximal flowers.

8. All flowers as originally developed are potential hermaphrodites and femaleness is positively correlated with the meristematic activity operating during the laying down of these organs.

9. The number of flowers capable of giving rise to fruit is thus dependent on the amount of meristem present and on its ability to function at the appropriate time in the history of the flower. Plants growing concurrently, with meristems of the same original potential, will produce flowers at the same time; and, as the ability to function is dependent very largely on the prevailing climatic conditions, bunches which are produced concurrently tend to carry the same number of female flowers. Any unevenness in the size of the original meristem may be offset if the leaves do not function for the same periods; but this cannot give rise to great differences in the number of female flowers produced, since the ability of the meristem to function will be approximately the same in all plants budding at the same date.

10. Differences may occur, however, for the number of female flowers is dependent too on the length of time over which the meristem is operating. This time depends on the period elapsing between the differentiation of successive buds from which the bracts arise. In the early portion of the period during which the flowers are being developed these bracts are budded at much the same rate as that at which the foliage leaves are extruded; but as the development proceeds the rate increases, and thus after a time the interval between the buddings is too short to allow of femaleness being conferred to a sufficient degree to ensure the flower becoming a potential fruit producer. Further, the meristem is used up in the process. The number of fruit, then, through the number of hands, depends to a degree on the number of foliage leaves which the plant has still to develop after initiation of the first flower bud. The external conditions which favour increased meristematic activity are generally concurrent with those which lead to an increase in the rate at which leaves are developed, so that no very great differences normally occur between comparably placed hands in the bunches.

11. Climatic factors cause such extensive modifications in growth that direct comparisons between plants can be made only when they have experienced

the same climatic conditions over the whole of the period involved. Further, the comparisons would only be valid when the various plants are in the same stage of development.

12. All female flowers do not necessarily give rise to fruit and the size attained by the fruit also varies. It appears that both number and size of fruit depend on the supply of food which is available during the development of the fruit in Stage 3 of the development of the plant. The supply of food is dependent on the amount which has been elaborated and the rate at which it can be translocated. As budding in the first place is bound up with conditions which require a certain minimum of food to have been elaborated, it seems that the amount of food is rarely if ever the true limiting factor in the field. Translocation rate is bound up to a degree with the availability of soil moisture and thus climate can have a marked effect on the filling of the fruit and on its maturation.

13. If a particular material leads to an increase in the rate of growth and consequent development it must mean that this material is required in the soil for the proper nutrition of the plant; and, therefore, even though no effect may be produced on the size of any particular crop, the inclusion of this material in an artificial fertilizer is warranted. The ultimate effect, of course, would be an increase in the number of crops.

14. Though the number of bunches produced at any one time is too small to allow definite conclusions to be drawn, all the evidence suggests that the application of any mineral fertilizer cannot, of itself, materially affect the number of fruit which a banana plant will produce. Such treatments may, however, affect the rate at which the development of the plant is completed and may thus lead to an increase in the total production over a period of years.

From what has been said in Conclusions 13 and 14 it follows that the value of fertilizing bananas lies largely in the reduction of the time required to produce a crop and in increasing the number of crops which a particular piece of land will produce. There remains the possibility that the size of a crop may be increased owing to the production of larger fruit. The evidence obtained in this investigation is inconclusive on this point; and, as results indicate slight differences in favour of nutrients which brought about other benefits to the plants, the question needs further investigation.

15. Leaf areas and leaf persistence give a valid index of the general activity of the plant up to a certain stage; and, further, the differences between plants are brought about largely by development in the very early stages. For these reasons it is concluded that practically the whole of the information which a fertilizer experiment on bananas can normally yield can be obtained by measuring the leaf areas over a few months and taking account of the life of the leaves. Measuring can be discontinued as soon as the relative increase in any month after the second becomes similar in all plants, for by that time the formative sub-stage is completed and the future of the plant so far as mineral nutrients can be of moment is fixed.

16. If it is desired to obtain information on the relative value of two treatments so far as efficiency of fruit production is concerned, bunches must

be obtained in sufficiently large numbers at the one time or the experiment must be carried on over a sufficiently long period to allow of the assessment of climatic influences.

17. Nitrogen metabolism must be given special consideration and in any investigation on the use of nitrogenous manures it would always be necessary to ensure that the nutrient is constantly available to the plant. Nitrogen in the soil is subject to more rapid reduction than are most other nutrients and steps should be taken to guard against any rapid changes. However, in initial qualitative work nitrogen would be subject to the points given in Conclusion 15.

18. The primary object of the investigation was to obtain information on the basic facts of nutrition rather than to gather data concerning the value of any particular artificial fertilizer. That is to say, the work was designed and carried out to discover what methods must be employed in fertilizer experiments on the banana. However, the technique was such that some information on the value of certain manures was obtained and this can be summarized as follows:—

(*a*) On the red basaltic loam on which the field trial was located, and which is typical of a large area of actual and potential banana-growing land in Queensland, sulphate of potash was associated with stimulated growth rate and faster development. Superphosphate did not appear to have been of any benefit but it should be noted that the fixation of phosphate is an important factor in this soil. With sulphate of ammonia no results which could be quantitatively assessed were obtained, but observational evidence suggested that where this material was applied alone the effect was distinctly bad. The plants seemed to lack vigour and the bunches were poor in general appearance. On the other hand, where nitrogen and potash were combined the plants and bunches had a much better appearance.

(*b*) The time of application of fertilizer is obviously of the utmost importance and where mineral nutrients are being used these must be applied early in the life of the plant. In most instances this would mean fertilizing twice or perhaps three times each year, for the suckers are generally allowed to come away in groups as regards time.

(*c*) There is no evidence that the age of the sucker materially affects the number of fruit which the parent plant produces.

(*d*) It is evident that time of planting is of great importance. If the soil fertility is high and a stimulating fertilizer is used the planting should be carried out late in the summer; otherwise the more effective the fertilizer the greater the likelihood of the bunches being produced in poor climatic conditions. The logical conclusion would appear to be to plant on fertile soils early enough to allow the plants to become well established before the winter yet sufficiently late to ensure that they will be throwing flowers when temperatures

are high and when thunder-storms or monsoonal rains nearly always ensure fair to high soil moisture. One other advantage of late planting is that the soil moisture is almost invariably high in the late summer, thus ensuring that the formative sub-stage will be passed in good conditions.

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APPENDIX 1.

Calculation of Ts of Plant.

This appendix is intended to serve as an example of the method of calculating Ts. The plant used in the example is No. 1A, the detailed records of which are included.

Area of Leaf x Number of Days Unfurled.

Leaf.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept. &c.
1 ..	81	..	..	..	..	..	..	..	..
2 ..	1,054	510	..	..	..	..	..	..	..
3 ..	2,212	2,212	..	..	..	..	..	..	..
4 ..	3,640	3,920	1,820	..	..	..	..	..	..
5 ..	4,394	4,732	2,197	..	..	..	..	..	..
6 ..	4,032	5,376	5,952	576	..	..	..	..	..
7 ..	3,538	5,992	6,634	6,420	214	..	..	..	..
8 ..	3,159	6,804	7,533	7,290	1,944	..	..	..	..
9 ..	1,338	6,244	6,913	6,690	4,906	..	..	..	..
10 ..	..	5,940	6,820	6,600	6,820	1,100	..	..	..
11 ..	..	4,200	6,510	6,300	6,510	1,050	..	..	..
12 ..	..	3,276	7,812	7,560	7,812	4,788	..	..	..
13 ..	..	1,716	8,866	8,580	8,866	7,436	..	..	..
14 ..	..	..	9,672	9,360	9,672	9,360	3,120	..	..
15 ..	..	..	9,050	10,860	11,222	10,860	3,260	..	..
16 ..	..	..	7,524	12,540	12,958	12,540	12,958	5,852	..
17 ..	..	..	5,357	14,610	15,097	14,610	15,097	13,636	..
18 ..	..	..	898	13,470	13,919	13,470	13,919	13,919	Plus
19 ..	..	..	..	11,160	14,415	13,950	14,415	14,415	Plus
20 ..	..	..	..	9,639	17,577	17,010	17,577	17,577	Plus
21 ..	..	..	..	5,895	20,305	19,650	20,305	20,305	Plus
22 ..	..	..	..	..	16,767	18,630	19,251	19,251	Plus
23 ..	..	..	..	..	10,125	20,250	20,925	20,925	Plus
24 ..	..	..	..	..	4,266	21,330	22,041	22,041	Plus
25 ..	..	..	..	..	..	12,274	22,382	22,382	Plus
26 ..	..	..	..	..	..	..	16,432	19,592	Plus
27 ..	..	..	..	..	..	..	1,168	18,104	Plus
28 ..	..	..	..	..	..	..	..	5,712	Plus
	23,548	50,922	93,558	137,550	183,395	198,308	203,210	213,711	Plus

Multiplying each monthly total by the hours of daylight and the mean temperature the products are:—

January	25,630,000
February	49,730,000
March	83,160,000
April	107,000,000
May	103,000,000
June	122,400,000
July	116,900,000
August	141,300,000
September, &c...	Plus
Ts (Final)	1,932,520,000

APPENDIX 1—continued.

BLOCK I, SUB. 1, TREATMENT O, STOOL NO. 1A.

Leaf.	Date Appeared.	Date Disappeared.	Area.	Total Area to Date.
			Sq. In.	Sq. In.
1	Jan. 1	Jan. 19	4·5	4·5
2	Jan. 1	Feb. 16	34	38·5
3	Jan. 3	Mar. 1	79	116·5
4	Jan. 5	Mar. 14	140	252·5
5	Jan. 7	Mar. 14	169	423·5
6	Jan. 11	Apr. 4	192	612·5
7	Jan. 15	May 2	214·5	827
8	Jan. 19	May 9	243	1,067
9	Jan. 26	May 23	223	1,287
10	Feb. 2	June 6	220·5	1,507·5
11	Feb. 9	June 6	210	1,717·5
12	Feb. 16	June 20	258	1,975·5
13	Feb. 23	June 27	286	2,261·5
14	Mar. 1	July 11	312	2,573·5
15	Mar. 7	July 11	362·5	2,936
16	Mar. 14	Aug. 15	418·5	3,354·5
17	Mar. 21	Aug. 29	487	3,841·5
18	Mar. 30	Sept. 19	449·5	4,291
19	Apr. 7	Oct. 3	465	4,756
20	Apr. 14	Oct. 24	567	5,323
		Oct. 31		
21	Apr. 22	Sept. 5	655·5	5,978·5
		Oct. 17		
22	May 5	Nov. 7	621	6,599·5
23	May 17	Oct. 24	675	7,274·5
		Nov. 7		
24	May 26	Dec. 12	711	7,985·5
25	June 14	Jan. 2	722	8,707·5
26	July 6	Jan. 23	632	9,339·5
27	July 30	Jan. 23	584	9,923·5
28	Aug. 20	Jan. 30	476	10,399·5
29	Sept. 2	Feb. 13	390·5	10,790
30	Sept. 19	Feb. 13	456	11,246
31	Sept. 29	Feb. 20	672	11,918
32	Oct. 9	Mar. 19	720	12,638
33	Oct. 20	Mar. 19	920	13,558
34	Nov. 6	Apr. 23	1,104	14,662
35	Nov. 15	Apr. 16	1,127	15,789
36	Nov. 27	Apr. 30	1,200	16,989
37	Dec. 5	Apr. 30	1,296	18,285
38	Dec. 14	.. ..	1,352	20,637
39	Dec. 23	..	1,404	22,041
40	Jan. 1	..	1,404	23,445
41	Jan. 12	..	1,323	24,768
42	Jan. 16	..	902	25,670

APPENDIX 2.

AREA OF LEAF IN SQUARE INCHES PRODUCED BY END OF EACH MONTH.

Plant No.	Treatment O.					
	Jan.	Feb.	Mar.	Apr.	May.	June.
1A	1,507	2,573	4,291	6,410	8,213	9,191
1B	Reject Plant					
15A	1,036	2,390	5,117	7,681	9,388	10,893
15B	1,170	2,622	6,497	9,269	11,400	12,663
23A	1,177	2,174	4,582	7,090	9,219	10,588
23B	1,472	2,783	5,772	8,720	11,456	13,138
28A	1,099	2,437	4,748	6,962	8,840	10,386
28B	Reject Plant					

Plant No.	Treatment O.					
	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1A	9,923	10,759	12,051	14,327	17,627	22,041
1B	Reject Plant					
15A	11,814	13,882	14,693	17,329	20,931	26,795
15B	13,493	14,819	15,396	17,847	Bunch	..
23A	11,711	12,811	14,591	17,296	23,105	Bunch
23B	14,469	15,628	17,424	20,018	Bunch	..
28A	11,318	12,426	13,912	16,436	20,245	24,100
28B	Reject Plant					

Plant No.	Treatment N.					
	Jan.	Feb.	Mar.	Apr.	May.	June.
6A	994	1,876	3,598	5,445	7,219	8,416
6B	1,356	2,246	4,082	6,007	7,999	9,037
12A	1,094	2,172	5,122	7,646	10,131	11,545
12B	1,094	2,040	4,300	5,984	7,878	8,633
20A	1,784	3,771	7,967	12,564	15,621	16,983
20B	1,276	2,582	5,513	7,816	10,028	11,182
30A	690	1,797	4,215	6,264	8,333	9,485
30B	688	1,760	3,676	5,798	8,010	9,032

Plant No.	Treatment N.					
	July.	Aug.	Sept.	Oct.	Nov.	Dec.
6A	9,226	10,146	11,405	13,615	16,531	20,804
6B	10,038	10,877	12,152	14,331	17,387	21,396
12A	13,138	13,990	15,147	17,285	Bunch	..
12B	9,406	10,332	11,587	13,349	16,268	20,682
20A	18,053	19,523	21,114	Bunch	..	..
20B	12,371	13,251	14,705	16,965	Bunch	..
30A	10,455	11,225	12,471	14,899	18,477	22,008
30B	10,065	11,152	12,676	14,702	18,421	23,363

APPENDIX 2—continued.

AREA OF LEAF IN SQUARE INCHES PRODUCED BY END OF EACH MONTH—*continued.*

Plant No.	Treatment P.					
	Jan.	Feb.	Mar.	Apr.	May.	June.
7A	1,350	2,762	5,773	8,216	10,975	12,640
7B	1,132	2,042	2,726	5,678	7,649	8,949
9A	922	1,932	4,140	6,636	9,328	10,688
9B	885	1,208	2,970	5,196	7,253	8,704
19A	2,094	4,497	8,376	12,250	14,956	16,449
19B	1,716	3,725	7,310	10,402	13,708	15,779
31A	1,310	2,207	3,797	5,958	8,228	9,217
31B	Reject Plant					

Plant No.	Treatment P.					
	July.	Aug.	Sept.	Oct.	Nov.	Dec.
7A	13,919	15,123	17,810	19,300	Bunch	..
7B	9,771	10,809	12,323	14,377	17,991	23,073
9A	11,688	12,668	14,132	17,002	21,180	26,449
9B	9,495	10,403	12,014	14,573	17,989	23,033
19A	17,501	18,677	20,976	Bunch	..	..
19B	16,577	17,692	19,456	Bunch	..	..
31A	10,138	11,104	12,491	14,753	18,304	22,982
31B	Reject Plant					

Plant No.	Treatment K.					
	Jan.	Feb.	Mar.	Apr.	May.	June.
8A	1,274	2,446	5,362	7,442	9,816	11,205
8B	1,000	1,862	4,093	6,033	8,306	9,896
11A	1,175	2,924	6,537	2,917	11,891	13,689
11B	1,393	3,249	6,598	9,189	12,479	14,293
18A	1,303	3,187	6,581	10,030	13,045	14,377
18B	1,688	3,118	6,490	10,071	13,137	14,581
32A	Reject Plant					
32B	1,100	2,660	5,485	7,554	9,622	10,597

Plant No.	Treatment K.					
	July.	Aug.	Sept.	Oct.	Nov.	Dec.
8A	12,279	13,442	14,744	17,234	20,886	25,332
8B	10,172	11,651	13,069	15,274	18,733	14,101
11A	15,253	17,044	18,689	21,798	Bunch	..
11B	15,428	16,814	18,641	21,474	Bunch	..
18A	15,425	16,677	18,090	20,951	Bunch	..
18B	15,862	16,964	17,703	21,357	Bunch	..
32A	Reject Plant					
32B	12,606	12,861	13,996	15,880	19,372	24,018

APPENDIX 2—continued.

AREA OF LEAF IN SQUARE INCHES PRODUCED BY END OF EACH MONTH—*continued.*

Plant No.	Treatment NP.					
	Jan.	Feb.	Mar.	Apr.	May.	June.
2A	441	851	2,177	3,821	5,752	6,130
2B	640	1,326	3,797	6,667	9,617	11,792
13A	961	1,787	3,712	5,484	7,352	8,592
13B	825	1,549	3,060	4,940	6,782	7,995
24A	869	1,706	3,674	5,551	7,515	8,950
24B	1,248	2,944	6,666	10,207	13,084	14,739
27A	1,298	2,322	4,640	6,663	8,584	9,536
27B	1,486	2,619	4,782	7,066	9,246	10,346

Plant No.	Treatment NP.					
	July.	Aug.	Sept.	Oct.	Nov.	Dec.
2A	8,067	8,967	10,570	12,895	14,874	20,233
2B	13,132	14,432	16,323	19,070	22,876	Bunch
13A	9,828	10,198	11,433	13,955	17,473	22,833
13B	8,744	9,543	10,801	13,080	17,520	22,610
24A	9,849	10,802	12,377	14,023	17,997	23,097
24B	16,100	17,463	19,494	Bunch	..	..
27A	10,474	11,251	12,374	14,503	17,985	22,644
27B	11,387	12,351	13,826	16,289	19,782	23,956

Plant No.	Treatment NK.					
	Jan.	Feb.	Mar.	Apr.	May.	June.
3A	1,014	2,237	4,984	8,101	11,035	12,839
3B	1,690	3,074	7,158	9,287	12,577	14,530
14A	1,101	2,699	5,932	9,319	12,369	13,870
14B	1,318	3,063	5,594	8,075	10,523	12,303
21A	Reject Plant					
21B	1,556	3,095	6,260	9,513	12,235	14,379
26A	651	1,368	3,185	5,341	7,579	8,632
26B	1,218	2,443	5,023	7,402	10,018	11,181

Plant No.	Treatment NK.					
	July.	Aug.	Sept.	Oct.	Nov.	Dec.
3A	14,073	15,582	17,302	19,969	23,378	Bunch
3B	15,943	17,323	19,192	Bunch	..	..
14A	15,216	16,605	18,282	Bunch	..	..
14B	13,254	14,521	16,052	17,370	Bunch	..
21A	Reject Plant					
21B	15,677	17,341	18,794	21,751	Bunch	..
26A	9,632	10,547	11,992	14,399	18,446	24,118
26B	12,298	13,907	15,043	17,620	21,564	Bunch

APPENDIX 2—continued.

AREA OF LEAF IN SQUARE INCHES PRODUCED BY END OF EACH MONTH—*continued.*

Plant No.	Treatment PK.					
	Jan.	Feb.	Mar.	Apr.	May.	June.
4A	716	1,733	4,453	7,609	10,743	12,211
4B	1,090	3,055	6,441	9,750	13,126	15,095
16A	662	1,324	3,163	4,967	7,070	8,418
16B	886	1,620	3,343	5,049	7,051	8,282
22A	1,293	2,917	5,509	8,373	10,753	12,008
22B	1,438	2,795	5,932	8,294	10,886	12,292
25A	832	2,007	4,817	7,909	10,330	11,385
25B	1,274	2,704	6,707	10,046	12,783	14,636

Plant No.	Treatment PK.					
	July.	Aug.	Sept.	Oct.	Nov.	Dec.
4A	13,626	14,988	16,075	19,206	23,145	Bunch
4B	16,858	18,263	20,488	23,123	Bunch	..
16A	9,354	10,260	11,875	14,065	17,687	22,449
16B	9,184	10,134	11,687	13,959	17,640	22,510
22A	13,059	14,085	15,610	17,982	Bunch	..
22B	13,494	14,661	16,487	18,944	21,040	Bunch
25A	12,128	12,238	14,565	17,166	21,236	26,488
25B	15,956	17,563	19,511	21,317	Bunch	..

Plant No.	Treatment NPK.					
	Jan.	Feb.	Mar.	Apr.	May.	June.
5A	976	1,943	3,746	5,874	7,776	8,756
5B	1,121	1,960	3,039	4,301	5,811	6,657
10A	860	1,788	3,900	5,958	8,376	10,010
10B	1,464	3,076	6,616	9,550	12,661	14,323
17A	938	1,998	4,525	6,791	9,156	10,496
17B	1,244	2,858	6,074	9,387	12,445	14,479
29A	609	1,608	3,520	5,901	7,875	8,937
29B	1,646	3,266	6,631	9,588	13,057	15,125

Plant No.	Treatment NPK.					
	July.	Aug.	Sept.	Oct.	Nov.	Dec.
5A	9,743	10,710	12,196	14,401	18,162	22,408
5B	7,301	7,948	9,345	10,886	14,243	18,757
10A	11,056	12,009	13,645	16,324	20,497	24,009
10B	15,630	17,081	18,750	Bunch	..	..
17A	11,335	12,160	13,627	15,903	19,782	23,597
17B	15,830	17,121	18,892	21,640	Bunch	..
29A	9,930	10,738	12,191	14,681	18,624	22,686
29B	16,381	17,750	19,550	22,676	Bunch	..

APPENDIX 3.

Analysis of Variance of Percentage Increase in Leaf Area, January–February.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Blocks	7	7,096·36	1,013·77
N	1	2·64	2·64
P	1	467·64	467·64
K	1	6,703·52	6,703·52
N x P	1	40·64	40·64
N x K	1	735·77	735·77
P x K	1	1,164·52	1,164·52
Error	18	24,101·41	1,338·97
Between Whole Plots	31	40,312·48	..
Within Whole Plots	27	13,717·60	508·06
Total	58	54,029·98	..

F for K = 5·01, which is significant.
s.e. per plot = 25·87 = 12·41 per cent. G.M.
" Sampling " error per plot = 15·94 = 7·64 per cent. G.M.

APPENDIX 4.

Analysis of Variance of Total Leaf Area Produced to October 31, 1939.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Blocks	7	36,353·21	5,193·32
N	1	996·81	996·81
P	1	970·20	970·20
K	1	11,235·01	11,235·01
N x P	1	1,277·65	1,277·65
N x K	1	250·88	250·88
P x K	1	2,499·25	2,499·25
Error	18	41,639·73	2,313·32
Total	31	95,221·73	..

F for K = 4·86, which is significant.
s.e. per plot = 48·10 = 14·77 per cent. G.M.
s.e. of mean of 16 plots = 12·02 = 3·69 per cent. G.M.

APPENDIX 5.

Analysis of Variance of Ts of Plants.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Blocks	7	108,981	15,568
N	1	73,536	73,536
P	1	69,192	69,192
K	1	8,978	8,978
N x P	1	7,200	7,200
N x K	1	61	61
P x K	1	15,753	15,753
Error	18	413,062	22,948
Total	31	696,763	..

There are no significant values of F for treatments.
s.e. per plot = 151·5 = 7·79 per cent. G.M.
No significant differences.

APPENDIX 6.

Analysis of Variance of Periods to Budding, in Days.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Blocks	7	72,875·1	10,410·7
N	1	708·9	708·9
P	1	1,233·7	1,233·7
K	1	19,986·9	19,986·9
N x P	1	9,481·9	9,481·9
N x K	1	381·1	285·1
P x K	1	862·9	862·9
Error	18	44,338·4	2,463·2
Between Whole Plots	31	149,873·0	..
Within Whole Plots	28	67,616·5	2,414·9
Total	59	217,489·5	..

F for K = 8·11, which is significant.
s.e. per plot = 35·09 = 7·2 per cent. G.M.
" Sampling " error per plot = 34·75 = 7·1 per cent. G.M.

The s.e. of each entry in the body of the table is 12·4 and of each marginal mean 8·77. The corresponding differences necessary for significance at the 5 per cent. level are 37 and 26. The response to K was significant, the effect of the application of K being to reduce the period to budding.

In this analysis the "sampling" error is only slightly less than the experimental error and this fact complicates the interpretation of the results. The "sampling" error is derived from the differences between duplicate plants in the same plot, and is due largely to the heterogeneity between plants. The fact that this variation is as large as the experimental error means that, in testing for differences by using the latter estimate of error, differences at least as

large could be accounted for by intra-plot variability. In the circumstances the significance of the effect of K is somewhat doubtful. An examination of the components of the "sampling" error showed that it was fairly uniform from block to block; the variation between treatments was more marked, but still not significant.

APPENDIX 7.

Analysis of Variance of Periods to Flowering in Days.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Blocks	7	32,387·7344	4,626·8192
N	1	1,000·1406	1,000·1406
P	1	682·5156	682·5156
K	1	4,987·8906	4,987·8906
N x P	1	3,263·2656	3,263·2656
N x K	1	26·2656	26·2656
P x K	1	385·1406	385·1406
Error	18	22,574·9064	1,254·1615
Between Whole Plots	31	65,307·8594	..
Within Whole Plots	31	..	..
Total	62	30,453·5000	982·3710

There are no significant values of F for treatment effects.

None of the main effects is significant, but the decrease in the presence of K is approaching the necessary figure for significance. Though there are no significant interactions the individual differences in some cases exceed the critical differences. The most outstanding of these occurs with respect to NP—in the absence of P the period to bunching is shorter when N is applied and similarly the application of K produced a decrease when N was present and also when P was absent.

APPENDIX 8.

Analysis of Variance of Rate of Growth prior to Budding.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Blocks	7	7,678·97	1,097·00
N	1	124·28	124·28
P	1	270·28	270·28
K	1	1,725·78	1,725·78
N x P	1	472·78	472·78
N x K	1	75·03	75·03
P x K	1	344·53	344·53
Error	18	5,766·81	..
Total	31	16,458·22	..

F for K = 5·39, which is significant.
s.e. per plot = 17·9 = 7·1 per cent. G.M.

The response to K was positive and significant and there were no other significant differences.

APPENDIX 9.

ANALYSIS OF VARIANCE OF RATE OF GROWTH—STAGES 1 AND 2 COMBINED.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Blocks	7	51·2188	7·3170
N	1	26·2813	26·2813
P	1	57·7813	57·7813
K	1	47·5313	47·5313
N x P	1	2·5313	2·5313
N x K	1	1·5313	1·5313
P x K	1	16·5313	16·5313
Error	18	254·0625	14·1146
Total	31	457·4688	..

There are no significant F values for treatments.
s.e. per plot = 3·757 = 6·18 per cent. G.M.

APPENDIX 10.

ANALYSIS OF VARIANCE OF TOTAL LEAF AREAS PRODUCED.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Blocks	7	8,112·3886	1,158·9127
N	1	950·9514	950·9514
P	1	1,733·6814	1,733·6814
K	1	147·9264	147·9264
N x P	1	1,416·5814	1,416·5814
N x K	1	69·5139	69·5139
P x K	1	143·1014	143·1014
Error	18	10,254·3878	569·6882
Between Whole Plots	31	22,828·5323	..
Within Whole Plots	32	16,531·5950	516·0498
Total	63	39,342·1273	..

There are no significant F values.
s.e. per whole plot = 16·88 = 7·20 per cent. G.M.
" Sampling " error per whole plot = 16·06 = 6·85 per cent. G.M.

None of the main effects is significant. There is an indication that, in the presence of N, P produced an increase in area but such an increase cannot be accepted as a real effect.

NATURAL WATERS OF THE QUEENSLAND COASTAL BELT.

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SUMMARY.

1. A number of natural waters have been examined, some by complete analysis and others by partial analysis; the methods are given in detail, with notes on cloudy waters.

2. The data are presented in terms of various ionic ratios, and in comparison with the two great divisions of natural water—the ocean and the great rivers of the world.

3. Compared with those of the great rivers, the waters of the Queensland coastal area exhibit a low ratio of calcium to magnesium, of divalent to monovalent bases (cations), and of bicarbonate to chloride. All these anomalies reflect oceanic influence.

4. The application of the data to boiler feed supply is discussed briefly. It is concluded that silica is not unduly high for tropical conditions.

Introduction.

The sugar-cane-growing tract in Queensland is a relatively narrow strip following the coastline and at no point extending more than about 50 miles from the sea. Although the average annual rainfall within this tract varies from less than 40 inches to over 200 inches, it might be expected that the natural waters of the region would have something in common in respect of the kinds of dissolved substances as distinct from their concentration. Particularly is this the case in view of the established fact (Anderson, 1941; Teakle, 1937) that "cyclic salt" caught up from ocean spray may be carried many miles inland and dominate the mineral content of the rivers and ground waters. Since the relative amounts of various ions in a water supply may often be of greater importance than the total amount of those ions, this paper aims at characterizing the waters of the Queensland coastal belt on the basis of ionic ratios, comparing them with the natural waters of other countries, and making what deductions are possible regarding their use.

The available data consist of a large number of partial analyses, and a smaller number of complete analyses in which all the ions commonly present were estimated or in which one ion was found by difference.

Methods.

(*a*) *Partial Analysis:*

Chlorides.—Titrate 50 ml. (10 ml. for brackish waters) with $^{N}/_{35}$ silver nitrate, using a few drops of 10 per cent. potassium chromate as indicator.

1 ml. $^{N}/_{35}$ $AgNO_3 = 0.00165$ g. NaCl;

Per cent. $\times$ 700 = grains per gallon (gr.p.g.).

Chlorides are here reported as grains of equivalent NaCl per gallon. This is justified by the absence of wide divergences in the $^{Na}/_{Cl}$ ratio of the waters analysed.

Total Alkalinity.—Titrate 100 ml. water, in an Erlenmeyer flask, with $^{N}/_{20}$ HCl, using as an indicator four drops of a 0·1 per cent. alcoholic solution of methyl red. (Acid waters are titrated with $^{N}/_{20}$ NaOH).

1 ml. $^{N}/_{20}$ HCl = 0·0025 g. $CaCO_3$.

In conformity with convention alkalinity is expressed as grains of $CaCO_3$ per gallon.

Total Hardness.—Take the titrated sample used for determining total alkalinity, heat to boiling point, and add 50 ml. of a $^{N}/_{20}$ alkali solution which contains equivalent parts of NaOH and Na_2CO_3. Bring the solution to the boil, cool, and transfer to a 200 ml. graduated flask. Make to the 200 ml. mark, and filter through an open paper. Titrate 100 ml. filtrate with $^{N}/_{20}$ HCl, after adding two more drops of indicator.

Treat 100 ml. distilled water in the same way for a blank determination.

In cases where the back-titration requires less than 10 ml. of $^{N}/_{20}$ HCl, the estimation should be repeated, using 50 ml. water for both test and blank. This is to ensure that there is sufficient hydroxyl ion present to precipitate all the magnesium.

Hardness is calculated from the amount of alkali consumed and is reported as grains of $CaCO_3$ per gallon.

Free Alkali.—When Total Alkalinity exceeds Total Hardness the excess is due to Free Alkali, which is also expressed as $CaCO_3$.

(*b*) *Complete Analysis.*

Chlorides.—Determine as for partial analysis, but report as milliequivalents of Cl per litre.

Carbonate and Bicarbonate.—Test 100 ml. water for presence of carbonate with a few drops of 1 per cent. alcoholic solution of phenolphthalein and if necessary titrate with $^{N}/_{20}$ HCl till colourless. Proceed with the methyl red titration as in partial analysis under "Total Alkalinity." Report as milliequivalents of HCO_3 (or CO_3) per litre.

Sodium.—

Reagent: 30 g. uranyl acetate ($2H_2O$);
90 g. zinc acetate ($3H_2O$);
27 ml. 30 per cent. acetic acid;
243 ml. distilled water.

Weigh the salts into a flask, add the acetic acid, then the water, and warm till dissolved. Filter before use.

Evaporate 25 ml. water (less if Cl exceeds 5 m.e. per litre) to dryness in a porcelain basin. Ignite gradually till the floor of the furnace is dull red,

and then for a further ten minutes to char organic matter. Cool, extract the contents several times with distilled water, using gentle heating, and filter using an acid-washed paper and a porcelain receiving dish. (A coloured extract indicates that the igniting must be repeated). Evaporate filtrate to dryness, add 1 ml. of distilled water and 10 ml. reagent; cover well to prevent evaporation, and let stand for four hours. Filter through a glass filter (grade 1G3), sucking the precipitate dry before washing several times with 95 per cent. alcohol saturated with the triple sodium salt. Wash twice with ether and stand in a warm place till ether has evaporated. Cool and weigh.

Wt. of precipitate × 0·65 = m.e. Na.

Silica, Sesquioxides, etc.—Evaporate 500 ml. water to dryness, flood the residue with conc. HNO_3, and evaporate dry. Repeat this twice with 20 per cent. HCl, and bake on a hot plate for one hour. Take up in 20 per cent. HCl and warm water, so that only flocculent silica (but no granular salts) remains undissolved. Filter through an open paper. Wash the filter well, dry, and gently ignite in a platinum dish, increasing the heat until a clear ash is obtained. Cool and weigh. Report as p.p.m. SiO_2. Make the filtrate to a known volume for determination of sesquioxides.

(Silica may also be determined with sufficient accuracy by a colorimetric method (Queensland Department of Agriculture and Stock, Bureau of Sugar Experiment Stations, 1939, p. 146)).

Treat one-half of the filtrate with a few ml. of bromine-water and boil off the fumes. Add more bromine-water, and then add ammonia until fuming in the mouth of the beaker ceases. Add 5 g. NH_4Cl and completely neutralize with ammonia. Bring to boil and filter through an open paper. Wash precipitate well with 2 per cent. ammonium nitrate solution made just alkaline with ammonia. Ignite and weigh the precipitate as for SiO_2 determination.

Calcium.—Boil the filtrate from sesquioxide determination till, on adding HCl and methyl red, the indicator still retains its red colour. Add 10 ml. saturated ammonium oxalate solution and gradually bring to a yellow colour with ammonia. Stand overnight, filter, and wash precipitate repeatedly till the washings have ceased to reduce acidified permanganate. Then dissolve the precipitate in dilute H_2SO_4, add 20 ml. conc. H_2SO_4, and titrate with $^N/_{20}$ $KMnO_4$.

Titration × 0·05 = m.e. Ca.

Magnesium.—Concentrate the calcium filtrate to 100 ml., add 10 ml. $^N/_2$ sodium dihydrogen phosphate and, stirring vigorously, add ammonia to an excess of 20 ml. 5N solution. Stand overnight. Filter through asbestos in a Gooch crucible, wash with 2 per cent. ammonia, dry in an oven, ignite strongly for 20 minutes, cool and weigh.

Wt. of precipitate × 17·96 = m.e. Mg.

Sulphate.—Boil the other half of the filtrate from the silica determination and add 5 ml. $^{N}/_{2}$ $BaCl_2$ drop by drop. Stand overnight. Filter through the finest paper, wash, and ignite as for SiO_2.

$$\text{Wt. of precipitate} \times 8{\cdot}57 = \text{m.e. } SO_4.$$

Potassium.—Take 500 ml. water and determine potassium by the platinic chloride method (Queensland Department of Agriculture and Stock, Bureau of Sugar Experiment Stations, 1939, p. 154).

Discussion of Methods.

Analysis of Coloured and Cloudy Samples.—Soil colloids readily absorb methyl red indicator, and soluble organic matter masks its colour. Experiments, as shown in Table 1, were carried out on clear samples of known analysis to determine the effects of various clarifying treatments. The agents used were B.D.H. acid-washed kieselguhr, Merck's X-ray grade barium sulphate, and Merck's bone char, each at the rate of 1g.-2½ g. per 100 ml. water. The samples were either centrifuged or filtered through a Whatman's No. 4, a Whatman's No. 50, or a "Postlip" No. 633 filter paper. The results of the experiments indicated that—

(1) Centrifuging with either barium sulphate or kieselguhr resulted in a colloidal condition;

(2) Filtration alone was more effective with an open paper (No. 4) than with a close one (No. 50);

(3) 1 per cent. kieselguhr treatment and filtration through No. 4 paper gave sparkling solutions. The disturbance due to filtration was usually enough to lower the bicarbonate content; and kieselguhr, besides having the most desirable qualities in producing bright solutions, had little other effect on the composition of the water.

Table 1.

Effect of Clarifying Agents on Analysis of Waters.

Water.	Treatment.	Chlorides (as NaCl.).	Total Alkalinity.	Total Hardness.	Free Alkali.
Mossman Mill—		gr. p.g.	gr. p.g.	gr. p.g.	gr. p.g.
Well Water	Filtration only (Whatman's No. 50)	3·3	..	1·1	1·0
	1 % kieselguhr ..	3·3	..	0·9	1·55
A. J. Jacobsen, Graham's Creek	None (cloudy water)	..	0·1	—0·2	..
	1 % kieselguhr ..	..	0·4	0·4	..
Mixed Burdekin Waters	None	..	..	10·2	..
	Filtration only (" Postlip " paper)	..	..	9·9	..
B. Tapiolas, Ayr ..	None	..	..	4·5	..
	Filtration only (" Postlip " paper)	..	..	4·4	..
Synthetic Irrigation Water	None	..	..	5·2	..
	Filtration only (" Postlip " paper)	..	..	5·1	..

Table 1—continued.

Effect of Clarifying Agents on Analysis of Waters.

Water.	Treatment.	Chlorides (as NaCl.).	Total Alkalinity.	Total Hardness.	Free Alkali.
		gr. pg.	gr. pg.	gr. pg.	gr. pg.
Mixed Burdekin Waters	None	..	10·2	9·45	0·75
	1% kieselguhr + 1% bone char ..	..	9·7	8·4	1·3
B. Tapiolas, Ayr ..	None	12·0	4·5	17·7	..
	1% kieselguhr + 1% bone char ..	12·35	4·5	17·0	..
Synthetic Irrigation Water	None	10·6	5·2	5·25	..
	1% kieselguhr + 1% bone char ..	10·9	5·2	5·4	..
Brisbane Water Supply (12–9–39)	None	9·7	7·4	12·1	..
	1% kieselguhr + 2½ % bone char ..	9·7	7·0	10·7	..
Brisbane Water Supply (6–12–30)	None	..	8·6	13·5	..
	1% bone char ..	..	8·0	13·3	..
Brisbane Water Supply (13–4–31)	None	..	5·0	7·4	..
	1% bone char ..	..	4·2	6·7	..
Brisbane Water Supply	None	..	7·7	..	..
	Filtration only ..	..	7·6	..	..
	1% kieselguhr ..	..	7·5	..	..
J. Toft, Avoca	1% kieselguhr ..	4·0	7·9	7·4	0·5
	1% kieselguhr + $BaSO_4$	3·6	7·3	6·3	1·0
J. H. Muir, Seaforth (1)	None	29·9	15·9	7·2	8·7
	Filtration only ..	29·9	15·8	..	..
	1% kieselguhr ..	29·9	15·8	6·65	9·15
J. H. Muir, Seaforth (2)	None	50·0	13·9	11·9	2·0
	Filtration only ..	50·2	13·7	11·4	2·3
	1% kieselguhr ..	51·2	13·7	11·0	2·7
Distilled Water	None	0·3	0·2	0·4	..
	Kieselguhr	1·6	1·6	2·6	..

The preferred method of treatment for a cloudy water which will not clear by standing or by direct filtration is, therefore, to add 1 per cent. of kieselguhr and filter through an open paper. The flocculent precipitate formed in the hardness estimation automatically leaves the solution clear for subsequent titration.

For more accurate work, and when colour is not easily removed, chlorides are estimated by the electrometric method (Best, 1929); and bicarbonates by a titration curve, using the glass electrode.

Value of Partial Analysis.—It may be noted that Total Hardness determined by partial analysis gives a good estimate of Ca + Mg as found by complete analysis. This is shown in Table 2. In the case of the sample Composite V it was found that the precipitate in the partial analysis contained silica

equivalent to 1·1 grains per gallon, suggesting that the slightly higher values for Total Hardness usually given by partial analysis may be due to co-precipitated silica.

Table 2.

Showing Accuracy Attained in Partial Analysis.

Water.	Total Hardness.	
	By Partial Analysis.	From Ca + Mg Equivalent.
	gr. p.g. $CaCO_3$.	gr. p.g. $CaCO_3$.
Lab. 576, Fairymead Plantation—No. 1 Dam	2·1	1·6
Lab. A. 2176, North Eton Mill—Loco. Supply	7·0	6·9
Composite V. Mixed Burdekin Waters	7·3	6·2
Lab. A. 1437, Sarina Distillery—Boiler Feed	10·7	9·3
Irrigation Water	11·1	8·9
Composite XVII., Mixed Burdekin Waters..	12·7	12·8
Lab. 851, Qunaba Plantation—Irrigation Supply	55·0	49·7

The partial analysis may also be used to obtain an approximate value of the important $\frac{Ca + Mg}{Na + K}$ ratio. Total Hardness is substituted for Ca + Mg, and the Chloride content is used as an indication of the alkalis present. The justification for the latter assumption lies in the fairly constant approach of the ratio $^{Na}/_{Cl}$ to unity, as shown in Table 5, and the negligible amount of K in natural waters. Before the $\frac{Ca + Mg}{Na + K}$ ratio can be calculated the Total Hardness and the Chloride content must be converted to chemically equivalent values. The conversion gives the equations:—

$$\frac{Ca + Mg}{Na + K} = \frac{\text{Total Hardness}}{50} \times \frac{58{\cdot}5}{\text{Chloride}} = \frac{\text{Total Hardness}}{\text{Chloride}} \times 1{\cdot}2.$$

The writer has shown (Cassidy, 1944) that the value of the $\frac{Ca + Mg}{Na + K}$ ratio determines the quality of an irrigation water and the effect it will have on the replaceable bases of a soil. Since the divalent bases produce desirable physical properties in a soil, whilst the monovalent bases have the reverse effect, the importance of the ratio from the agricultural aspect is apparent.

Discussion of Data.

Composition of Waters.—Table 3 presents data on waters from various parts of coastal Queensland, representing either sugar mill boiler-feed supplies or farmers' irrigation water. The concentrations of the various ions are given as milliequivalents per litre, and in Table 4 they are expressed as a percentage of the total ion content. This means that only the relative proportions of the ions present need be considered and that the actual concentration of salts in the water may be disregarded. The relative values for some

southern Australian rivers and water-supplies are also given, as well as those for sea water and for the mean of the great rivers of the world (Clarke, 1924).

Table 3.

ILLUSTRATING THE COMPOSITION OF SOME QUEENSLAND COASTAL WATERS.

Lab. No.	Water.	HCO_3	Cl	SO_4	Ca	Mg	Na	K
		(Milliequivalents per litre).						
A.2020	Meringa Experiment Station ..	0·27	0·29	0·03	0·08	0·18	0·24	0·04
	Racecourse Mill—							
561	Supply Tank	1·17	0·52	0·09	0·9		0·88	
562	Pump Delivery	1·17	0·44	0·09	1·0		0·70	
A.1037	Farleigh Mill—Foulden Supply	1·05	0·50	0·14	0·60	0·35	0·73	0·03
A.1437	Sarina Distillery—Boiler Feed ..	2·42	1·75	0·16	1·52	1·13	1·25	..
A.2176	North Eton Mill—Loco. Supply ..	1·08	2·34	0·36	1·12	0·87	1·73	0·07
A.2203	Ollett Bros., Habana—Well ..	5·40	3·36	0·10	4·24	1·65	2·79	..
A.2187	W. E. Kelly, Hebron	1·18	1·71	0·86	1·38	1·52	0·85	..
	Qunaba Plantation—							
851	Irrigation Supply	4·12	21·51	3·66	3·99	10·18	12·62	0·27
	Fairymead Plantation—							
576	No. 1 Dam	0·93	2·11	0·14	0·20	0·25	2·7	..
635	Old Irrigation Plant, No. 1 ..	4·12	5·72	..	3·92		..	..
636	Old Irrigation Plant, No. 2 ..	3·62	5·47	..	4·09		..	..
	Fairymead Mill—Boiler Supply—							
A.1103	No. 1	0·72	2·09	..	0·27	0·49	..	..
A.1104	No. 12	20·82	5·58	0·80	0·50	1·42	5·28	..
A.1115	No. 2	0·90	2·58	0·63	0·20	0·53	3·38	..
A.1146	No. 2 (Repeat)	0·72	2·70	0·58	0·07	0·35	3·58	..
..	Brisbane Water Supply	1·48	1·67	0·27	1·17	0·62	1·71	..
..	Hawaiian Irrigation Waters (Aver.)	0·98	1·13	0·25	0·55	0·67	1·04	0·10

The sharp contrast between the composition of sea water and that of the great rivers is evident. Whilst sea water is dominated by sodium and chloride ions, the great rivers are dominated by calcium and bicarbonate. The waters of the Queensland sugar-cane-growing areas are intermediate in composition. This is well illustrated in Table 5, where ratios of one ion to another are given. These ratios emphasise the radical differences in composition between sea water and the great river waters. Anderson (1940) has stressed the equivalence ratio of $^{Na}/_{Cl} = 0{\cdot}85$ as the characteristic of sea water, but Table 5 shows three other ratios demonstrating better the unique character of sea water among natural waters. This is doubtless due to the removal of calcium carbonate from the incoming river waters by sea organisms. The average $^{HCO_3}/_{Cl}$ ratio of 7 for river waters is thus reduced in sea water to a negligible value. The last column of the table shows that all the Australian waters listed have a $^{HCO_3}/_{Cl}$ ratio much lower than that of the average for world river waters. The low content of calcium *in relation to magnesium,* and of the divalent

bases in relation to the monovalent, is shown in the centre columns of the table. A large number of waters have been examined only by the partial method of analysis but they show a general conformity to the type revealed by the

Table 4.

COMPARING WATERS OF THE QUEENSLAND COAST WITH VARIOUS OTHER NATURAL WATERS.

Water.	HCO_3	Cl	SO_4	Ca	Mg	Na	K
	(Per Cent. of Total Milliequivalents.)						
Rivers Waters (World)	36·6	5·0	7·9	31·9	8·7	7·8	1·7
Sea Water	0·2	45·2	4·6	1·7	8·9	38·5	0·8
Queensland Sugarcane-growing Areas—							
Meringa Experiment Station	23·9	25·8	2·7	7·0	15·9	21·2	3·5
Racecourse Mill—Supply Tank	32·9	14·6	2·5	25·3		24·7	
Farleigh Mill—Foulden Supply	30·9	14·7	4·1	17·6	10·3	21·5	0·9
Plane Creek Distillery, Sarina—							
August, 1934	23·8	23·7	2·4	19·8	9·6	20·6	..
April, 1936	29·4	21·3	1·9	18·5	13·7	15·2	..
W. E. Kelly, Hebron	15·7	22·8	11·5	18·4	20·3	11·3	..
North Eton Mill—Loco. Supply	14·3	30·9	4·8	14·8	11·5	22·8	0·9
Ollett Bros., Habana—Well	30·7	19·2	0·6	24·2	9·4	15·9	..
Qunaba Plantation—Irrigation Supply	7·3	38·2	6·5	7·1	18·0	22·4	0·5
Fairymead Plantation—No. 1 Dam	14·7	33·3	2·2	3·2	4·0	42·6	..
Fairymead Mill—Boiler Supply—							
No. 12	5·7	38·6	5·6	3·5	9·9	36·7	..
No. 2	11·0	31·4	7·7	2·4	6·4	41·1	..
No. 2 (Repeat)	9·0	33·7	7·3	0·9	4·4	44·7	..
Other Queensland Waters—							
Copperfield River	34·7	15·3	0·0	16·5	18·2	15·3	..
Don River, Bowen	19·6	14·2	17·3	17·3	17·3	14·2	..
Dee River, Mount Morgan	14·5	23·3	12·2	12·2	19·2	18·6	..
Dawson River	23·5	24·3	2·2	25·7	16·3	8·0	..
Mary River (May, 1915)	23·7	26·3	0·0	11·8	19·1	19·1	..
Mary River (July, 1935)	10·6	35·4	4·0	6·9	22·3	20·8	..
Lockyer Creek	23·6	26·1	0·3	8·5	15·6	25·9	..
Tenthill Creek, Gatton	30·2	18·4	1·4	16·7	19·7	13·6	..
Brisbane River, Lowood (November, 1940)	15·4	32·5	2·1	10·9	17·1	22·0	..
Stanley River Dam	14·5	32·0	3·5	18·1	15·4	16·5	..
Brisbane Water Supply	21·4	24·1	3·9	16·9	9·0	24·7	..
Other Australian Waters—							
Sydney Water Supply	11·2	32·3	5·9	6·6	11·9	32·1	
Murray River, Merbein, Victoria	23·7	19·8	6·5	15·2	15·4	19·4	
Yarra River, Warrandyte, Victoria	15·4	30·2	2·4	9·1	13·2	25·7	3·2
Emu River, Burnie, Tasmania	15·6	29·1	4·6	16·6	5·6	23·3	5·3
Adelaide Water Supply	15·1	29·3	4·2	10·0	13·8	24·9	2·7
Canning River, West Australia	4·5	40·8	4·4	5·2	14·9	29·9	
Hawaiian Irrigation Waters (Average)	20·8	23·9	5·3	11·7	14·2	22·0	2·1

Table 5.

Characterizing the Type of Water by the Ratios of its Ions.

Water.	Na/Cl	Ca/Mg	$\frac{Ca + Mg}{Na + K}$	$\frac{HCO_3}{Cl}$
River Waters (World)	1·6	3·7	4·3	7·3
Sea Water	0·85	0·2	0·27	0·005
Queensland Sugarcane-growing Areas—				
Meringa Experiment Station	0·8	0·4	0·9	0·9
Racecourse Mill—				
Supply Tank	1·6	..	1·0	2·2
Pump Delivery	1·6	..	1·4	2·7
Farleigh Mill—Foulden Supply	1·5	1·7	1·2	2·1
Plane Creek Distillery, Sarina—				
August, 1934	0·9	2·1	1·9	1·0
April, 1936	0·7	1·3	1·7	1·4
North Eton Mill—Loco. Supply	0·7	1·3	1·1	0·5
Ollett Bros., Habana—Well	0·8	2·6	2·0	1·6
W. E. Kelly, Hebron	0·5	0·9	3·4	0·7
Qunaba Plantation—Irrigation Supply	0·6	0·4	1·1	0·2
Fairymead Plantation—				
No. 1 Dam	1·3	..	0·2	0·4
Old Irrigation Plant No. 1	..	..	..	0·7
Old Irrigation Plant No. 2	..	..	..	0·7
Fairymead Mill—Boiler Supply—				
No. 1	1·0	0·6	..	0·3
No. 12	0·9	0·4	0·4	0·1
No. 2	1·3	0·4	0·2	0·3
No. 2 (Repeat)	1·3	0·2	0·1	0·3
Other Queensland Waters—				
Copperfield River	1·0	0·9	2·3	2·3
Don River, Bowen	1·0	1·0	2·4	1·4
Dee River, Mount Morgan	0·8	0·6	0·7	0·8
Dawson River	0·3	1·6	5·3	1·0
Mary River (May, 1915)	0·8	0·6	1·6	0·9
Mary River (July, 1935)	0·6	0·3	1·4	0·3
Lockyer Creek	1·1	0·5	0·9	0·9
Tenthill Creek, Gatton	0·7	0·8	0·3	1·6
Brisbane River, Lowood (November, 1940)	0·7	0·6	1·3	0·5
Stanley River Dam	1·1	1·2	2·0	0·4
Brisbane Water Supply	1·0	1·9	1·0	0·9
Other Australian Waters—				
Sydney Water Supply	1·0	0·6	0·6	0·3
Murray River, Merbein, Victoria	1·0	1·0	1·6	1·2
Yarra River, Warrandyte, Victoria	0·8	0·7	0·8	0·5
Emu River, Burnie, Tasmania	0·8	3·0	0·8	0·5
Adelaide Water Supply	0·8	0·7	0·9	0·5
Canning River, West Australia	0·7	0·4	0·7	0·1
Hawaiian Irrigation Waters (Average)	0·9	0·8	1·1	0·9

complete analyses. For example, the ionic ratio of bicarbonate to chloride is usually less than unity. These facts are of considerable agricultural significance in their bearing on the use of water for irrigation; this aspect is discussed elsewhere (Cassidy, 1944).

Boiler-supply Water.—It is well known that the total amount of dissolved solids is of primary importance in water for steam-raising purposes, but that the sodium salts are of much less moment than are calcium and magnesium salts and silica. The Java Proefstation based its treatment of boiler waters on these facts by proportioning the dosage of tannin to the total hardness and to the silica present (see Queensland Department of Agriculture, Bureau of Sugar Experiment Stations, 1939, p. 144). It has been suggested that a boiler water will not deposit scale of any consequence if $SiO_2 + 2{\cdot}95$ Ca $+ 1{\cdot}66$ Mg is less than 300 p.p.m. In this formula Ca (in parts per million) has been calculated to a mixture of carbonate and sulphate, and magnesium to the oxide. This criterion was applied by the author to 63 cases cited by Paul (1923) and others, with the results shown in Table 6.

Table 6.

USEFULNESS OF FORMULA FOR PREDICTING SCALE-FORMATION IN BOILERS.

Designation.	Total Number.	Number Correctly Placed.	Average Coefficient, p.p.m.
Badly scaling waters ..	39	31	503
Non-scaling waters ..	24	22	173

Because sugar factories use relatively low-pressure boilers and a high percentage of condenser water, water-treatment plants are installed at very few Queensland sugar mills. The criterion given should therefore prove useful in testing the suitability of new supplies. The experience of Smith (1941) with boiler-water at an alcohol distillery is at variance with the rule given, but the high evaporation rate and the non-recovery of condensate in an alcohol distillery are probably responsible for the heavy scaling reported.

The presence of silica is important because it produces the hardest scale. Paul (*loc. cit.*) quotes cases of waters containing as much as 120 p.p.m. SiO_2, and tropical waters are commonly high in silica because of the effects of the particular soil weathering conditions. However, as shown in Table 7, the amount of silica present in Queensland coastal area waters is not high, although Kelly (1939) cites the unusual case of Kalamia mill water, in which the silica is present, not in the usual colloidal and uncombined state, but as sodium silicate and in fairly large amounts.

Liability to corrosion is not so readily predicted from chemical analysis; dissolved oxygen and the presence of much magnesium, accompanied by little bicarbonate ion, are factors favouring corrosion. Here again sugar factory practice averts most of the trouble and the maintenance of a sufficiently high pH in the boilers completes the control.

Table 7.

Silica Content and Scale-forming Factor for Various Waters.

Water.	SiO_2 (p.p.m.)	Ca (p.p.m.)	Mg (p.p.m.)	Coefficient (p.p.m.)
Mossman Mill	27	..	..	41*
Meringa Experiment Station	4	2	2	13
Racecourse Mill—Loco. Supply	28	..	..	593*
Racecourse Mill—Mount Ossa	16	..	..	120*
Farleigh Mill—Foulden Supply	29	12	4	71
Sarina Distillery—Boiler Feed	18	30	14	129
North Eton Mill—Loco. Supply	3	22	10	85
Kalamia Mill Supply	73	1·6	trace	78
B. Tapiolas, Ayr	24 55	..	..	270*
J. H. Muir, Seaforth	35 40	..	..	170*
J. Breen, Ayr—Lagoon	5	..	..	36*
Finn Bros., Home Hill	25	..	..	533*
G. Rogers, Peri	31	..	..	145*
Richards Plantation Creek	40	..	..	147*
Dick's Bank Lagoon	35	..	..	49*
Qunaba Plantation—Irrigation Supply	47	80	124	489
Fairymead Mill—				
No. 1 Pump	..	5	6	>25
No. 12 Pump	..	10	17	>58
No. 2 Pump	58	4	6	80
Brisbane Water Supply	24	23	8	105

* Derived from the Total Hardness + Silica.

Exceptional Waters.—In the preceding discussion attention has been confined for the most part to the normal waters of the region. There are, however, many instances of waters which fall outside the normal range because of some factor such as free acid, excess salt, or much free alkali. Examples are given in Table 8 of waters which would require special consideration. Only partial analyses are available, so Brisbane Water Supply is quoted in the same form for comparison.

Quite apart from these abnormal waters, there are waters in which the salt content is affected by heavy falls of rain following a dry period. Such waters usually return to normal as conditions become more regular, and the evidence on hand shows that ordinary fluctuations of this kind do not affect the major conclusion of this paper regarding the type of water, as demonstrated by the various ionic ratios shown in Table 5.

Need for Uniformity of Expression.—The fact that three systems of units—viz., grains per gallon, milliequivalents per litre, and parts per million—have had to be used in this paper draws attention to the need for uniformity of expression of analytical results, with chemically equivalent units as the only logical basis.

Table 8.

EXAMPLES OF EXCEPTIONAL WATERS.

Water.	Chlorides. (gr. p.g. NaCl)	Total Hardness. (gr. p.g.)	Free Alkali. (gr. p.g.)	Acidity. (gr. p.g.)
R. C. Quod, Proserpine	22	11	8	..
W. J. Nelson, Giru..	44	40	31	..
W. Moratt, Ayr	59	7	25	..
J. O. Jensen, Narpi, Mackay	25	31	10	..
Mullet Creek—Currajong	107	61	..	..
Mullet Creek—Well	446	42	..	3·5
Gin Gin—Creek	120	45	..	..
S. A. Wood, Bauple	9	2	12	..
Mount Bauple Mill	16	2	..	(pH 4·3)
Childers—Apple Tree Creek	170	51	..	..
Cordalba—Gregory River	170	42	..	..
H. H. Plath, Doolbi	306	66	..	(pH 4·0)
H. Cox, Horton	37	4	37	..
M. B. Fisher, Kolan R.—Creek	324	66	..	(pH 3·0)
M. B. Fisher, Kolan R.—Well	62	7	..	(pH 3·6)
Fairymead	19	3	31	..
H. J. Jacobsen, Graham's Creek, Maryborough	38	5	14	..
Brisbane Water Supply	6·8	6·3	..	..

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EXCHANGEABLE SODIUM AND THE PHYSICAL PROPERTIES OF SOILS.

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SUMMARY.

1. The chemical effect of an irrigation water upon a soil is shown to depend primarily on the $\frac{Ca + Mg}{Na + K}$ *value of the water, to a less extent on the total solids and the duty of water, and not at all on the previous irrigation history of the soil.*

2. The conditions for the entry of sodium into the exchange complex of irrigated soils are defined.

3. It is shown that free alkali (sodium bicarbonate) in an irrigation water has no particular activity ascribable to it except so far as it furnishes sodium ions.

4. The physical properties of a soil are not adversely affected by exchangeable sodium until it constitutes about 15 *per cent. of the total exchangeable bases. The deterioration is then rapid as sodium increases.*

5. The Keen-Raczkowski test, a simple percolation experiment, and a simple penetrometer were used to measure the physical degeneration of soils due to excess sodium.

6. Laboratory tests suggest that cultivation, particularly when the soil is dry, is more likely to be responsible for inducing bad physical characteristics in Burdekin soils that is salt accumulation resulting from saline irrigation waters. In each event the water-holding capacity of the soil, its air supply and its permeability are reduced; its hardness on setting is increased.

7. The natural waters of the Queensland coastal belt, having a rather low Figure of Merit as irrigation waters, need to be chosen with care in order to avoid puddled soils.

Introduction.

In assessing the suitability of a water for irrigation purposes it has been customary to accept a set of limiting values for the concentrations of salt, free alkali, or total solids. These limits have been fixed somewhat arbitrarily from general experience, but this method is unreliable and does not enable accurate conclusions to be drawn as to possible deleterious effects of a given water on the soil and therefore on crops.

The writer has used a different criterion for this purpose, and, as will be shown in the paper, it enables the true action of the water on the soil to be predicted with some certainty. This criterion, which has been termed the "Figure of Merit" of the water, is simply the ratio of the divalent ions calcium and magnesium to be monovalent ions sodium and potassium present in the

water, all expressed as chemical equivalents. If thus takes cognizance of the reversible nature of the base exchange reaction which occurs when the soil is irrigated. The alkalis (almost entirely sodium in a natural water) tend to produce a sodium soil by displacing calcium and magnesium from the soil: but this action is resisted by the divalent ions already present in the water. The state of equilibrium which is attained depends on the Figure of Merit of the water, and to a much smaller degree on the amount and kind of replaceable bases in the soil and the total weight of saline matter introduced by irrigation. This Figure of Merit (which will be referred to in this paper as f) is thus $\frac{Ca + Mg}{Na + K}$ and has previously been used by the writer (Cassidy, 1937, 1944) in surveys of the waters of the Queensland coastal belt.

Admittedly there are factors to be considered other than the effect of the water upon the soil: the tolerance of the plant to high osmotic pressures, the water-holding capacity of the soil, and the permeability of the soil to water, are all of vital concern. In the final analysis, however, these particular factors reduce to the same thing—the ability of the plant to tolerate the concentration of soluble salts that may be established in the soil—and this topic is not the concern of the present paper.

Laboratory Experiments.

The foregoing discussion has anticipated the results of experiments which were conducted to find the effect of salinity of various degrees and kinds upon the chemical composition of the soil. In a few cases field observations were utilized; here the effect of irrigation waters was gauged by the difference in composition evidenced in their drainage, or by analysing soil samples from two fields of the same soil before and after these fields had been subjected to irrigation waters of different composition. Generally, however, laboratory experiments were conducted in which a column of soil contained in a glass cylinder fitted with a cotton-wool filtering plug was leached slowly by either a natural or a synthetic irrigation water. The soil columns were usually about three or four inches long and the cylinders either two or three and a-half inches in diameter. In a few instances narrower cylinders and smaller amounts of soil were used. Leaching times were of the order of one acre-inch per hour, with a free drainage period overnight. After leaching, the soils were washed free of salts with 70 per cent. alcohol, air-dried, and replaceable bases determined. For this estimation a portion was extracted by continued leaching with 0·02N HCl and the various ions determined as described elsewhere (Cassidy, 1944).

In Table 1 are given details of the leaching solutions used in the laboratory experiments. The ionic concentrations are expressed as milli-equivalents per litre: from these the f value and the ratio of calcium to magnesium have been calculated. Finally, the total salt concentration has been given in terms of grains per Imperial gallon, since this unit is used by many workers, and where free alkali (sodium bicarbonate) is present the amount has been

Table 1.

ANALYSIS OF LEACHING SOLUTIONS USED.

Leaching Solution.	HCO_3	Cl	SO_4	Fe	Ca	Mg	Na	K	Total. cations.	Ca/Mg	$\frac{Ca+Mg}{Na+K}$	Total Solids. (Grains per Gallon.)
	(milli-equivalents per litre.)											
1. Irrigation Water—B. Tapiolas..	1·38	2·99	5·91	0·11	2·37	2·84	4·71	0·09	10·2	0·8	1·08	45
2. Synthetic	1·47	2·60	1·47	..	0·49	1·14	3·91	..	5·6	0·4	0·42	25
3. Synthetic—high alkali	3·59	1·79	0·60	0·07	0·59	0·00	5·31	..	6·0	..	0·11	30, including 11 gr. p.g. free alkali.
4. Synthetic—high alkali	3·41	3·26	Nil	..	0·46	0·22	6·00	..	6·7	2·0	0·11	33, including 10 gr. p.g. free alkali.
5. Synthetic—high alkali	3·70	2·51	Nil	..	0·26	0·13	5·84	..	6·2	2·0	0·07	30, including 12 gr. p.g. free alkali.
6. Synthetic—high salt	Nil	27·0	Nil	..	1·62	0·81	24·6	..	27·0	2·0	0·10	120
7. Brine	Nil	1,000	Nil	..	Nil	Nil	1,000	.. (H)	1,000	..	0·00	4,000
8. Synthetic—high salt	Nil	27·0	Nil	..	1·58	0·78	24·1	0·54	27·0	2·0	0·10	100 (acid) ; pH about 3.
9. Synthetic—very high salt ..	Nil	57·6	Nil	..	3·40	1·69	52·0	0·54 (K)	57·6	2·0	0·10	230 (acid) ; pH about 3.
10. Equivalent of diluted seawater	Nil	25·5	3·0	..	0·8	5·0	21·6	Nil	28·0	0·16	0·27	113
11. Synthetic—very high alkali ..	6·6	Nil	Nil	..	0·2	2·3	4·28	Nil	6·7	1·9	0·64	32, including 23 gr. p.g. free alkali.
12. Synthetic—high salt	Nil	25·1	4·2	..	7·35	7·35	14·2	0·2	29·2	1·0	1·02	112

Table 2.

DESCRIPTION OF SOILS USED IN LABORATORY EXPERIMENTS.

Soil.	Texture.	pH	Replaceable Bases. (m.e. per 100 g.)					Mechanical Analysis. (per cent.)			
			Ca	Mg	Na	K	Total.	Coarse Sand.	Fine Sand.	Silt.	Clay.
Burdekin Alluvial ..	Dark grey silty clay loam	6·16	14·6	6·5	0·88	0·71	22·7	13·9	40·6	20·9	24·6
Bellenden-Ker Alluvial	Yellowish brown silty loam	6·08	4·72	1·10	0·36	0·61	6·8	8·0	37·6	23·9	30·5
Bundaberg Red Forest	Red sandy loam ..	6·12	3·82	1·18	0·12	0·28	5·4	31·6	24·2	14·1	30·1

shown in the same units. The normal range of medium to high salinity encountered in irrigation waters is covered in Table 1, and waters of moderately high content of sodium bicarbonate are represented. A brine and two acid salty waters are also included. Water No. 10 is a representation of sea water diluted 20 times.

Two Burdekin soils, one a cultivated silty loam from B. Tapiolas and the other an adjacent virgin soil from Christofides and Kallas, were the soils principally used; a Bellenden-Ker alluvial and a Bundaberg red forest soil were also included in some of the experiments. The soils are described in Table 2.

Measure of the Change.—As a measure of the change produced in the soil it is better to express each exchangeable ion as a percentage of the total replaceable bases than as an absolute value. In this way it is possible to deal with the reactive part of the soil only and to minimise the effect of having included a greater or smaller amount of the sand fractions in the particular sample. Small changes in the total exchange capacity of the soil are likewise neutralized, whilst direct comparison between different soils is possible. The criterion chosen has been in all cases Na, and not Na + K, as percentage of total bases, since irrigation waters contain negligible amounts of K, precluding large increases of exchangeable K; moreover, in comparisons of virgin and cultivated soil K changes independently by virtue of its being an important plant food.

Results.—Table 3 presents the effects which the various irrigation waters had on the several soils used. It appears that under the conditions of the experiment 30 acre-inches of water were sufficient to produce most of the ultimate effect obtainable (see trials h and i). In the cases where only 20-25 acre-inches of leachate were used, the narrow cylinders and smaller amounts of soil employed probably gave as complete a state of equilibrium.

A study of Table 3 shows that the f value is the dominating factor determining the chemical status of the soil after leaching. Thus tests a and b indicate that the f values of the waters, and not the amounts of total solids, have determined the exchangeable sodium in the resulting soils when each received a 72 acre-inch application.

The actual effect of free alkali upon the soil is also made clearer. It has often been assumed that even a small amount of free alkali must be injurious in an irrigation water, and in a general way the effect of free alkali has been assumed to be four or five times as great as that of common salt. That these assumptions are not valid for the present enquiry is shown by the data now available. The results show that, with similar values of f and total solids, the higher the free alkali content the greater will be the absorption of sodium by the soil (see tests d, c and e). For waters with similar total solids content but different values of f (see tests l and e), the one with the higher f value has resulted in less sodium absorption by the soil than the other, even though the former contained double the free alkali content of the latter. Results of tests b and l corroborate this.

Table 3.

EFFECT OF IRRIGATION WATER UPON SOIL—LABORATORY EXPERIMENT.

Test.	Soil.	Leaching Solution.	Type of Irrigation Water.				Acre-in. Watering.	Resulting Soil. Replaceable Bases. (Per Cent. of Total.)				Change Produced. Replaceable Bases. (m.e. per 100 g.)		Designation of Resulting Soils.
			$\frac{Ca+Mg}{Na+K}$	Ca/Mg	Total Solids.	Free Alkali.		Ca	Mg	Na	K	Na	K	
					gr. p.g.	gr. p.g.								
	Burdekin Alluvial—													
..	B. Tapiolas, Ayr	..	..	..	..	..	Nil	64·1	29·8	4·3	1·8	..	..	Cultivated soil
a	Ditto	1	1·08	0·8	45	Nil	72	59·2	34·6	4·5	1·7	+0·12	..	..
b	Ditto	2	0·42	0·4	25	Nil	72	59·2	34·0	5·2	1·6	+0·30	..	..
c	Ditto	3	0·11	..	30	11	78	59·0	28·4	10·9	1·7	+1·55	..	..
..	Christofides and Kallas, Ayr ..	..	..	..	..	..	Nil	64·4	28·6	3·9	3·1	..	..	Virgin soil
d	Ditto	4	0·11	2·0	33	10	32	62·3	27·2	8·3	2·2	+1·06	−0·20	Soil E
e	Ditto	5	0·07	2·0	30	12	37	60·5	25·2	12·0	2·3	+2·16	−0·15	Soil C
f	Ditto	6	0·10	2·0	120	Nil	29	56·6	24·8	16·5	2·1	+3·18	−0·22	Soil D
g	Ditto	7	0·00	..	4,000	Nil	35	11·9	2·8	84·9	0·4	+17·0	−0·68	Soil F
h	Ditto	8	0·10	2·0	100	Acid	31	59·3	23·8	15·8	1·1	+2·99	..	Soil B_1
i	Ditto	8	0·10	2·0	100	Acid	67	58·5	23·2	16·8	1·5	+3·03	−0·38	Soil A
j	Ditto (Soil B_1) ..	9	0·10	2·0	230	Nil	37	60·0	17·3	21·4	1·3	+3·50	−0·46	Soil B_2
k	Christofides and Kallas, Ayr	10	0·27	0·16	100	Nil	20	54·2	35·2	9·2	1·4	+0·96	−0·42	Soil IA
l	Ditto	11	0·64	1·9	32	23	25	60·6	31·7	5·4	2·2	+0·30	−0·24	Soil IB
..	Bellenden-Ker Alluvial ..	..	..	..	..	Nil	..	..	70·4	16·4	5·4	7·8	..	..	Soil II
m	Ditto	10	0·27	0·16	100	Nil	20	34·4	41·8	18·4	5·4	+0·92	−0·14	Soil IIA
n	Ditto	11	0·64	1·9	32	23	25	52·0	29·2	12·4	6·4	+0·69	+0·02	Soil IIB
..	Bundaberg Red Forest ..	..	..	..	..	Nil	..	..	70·7	21·9	2·2	5·2	..	..	Soil III
o	Ditto	10	0·27	0·16	100	Nil	20	39·0	44·8	14·9	1·2	+0·72	−0·21	Soil IIIA
p	Ditto	11	0·64	1·9	32	23	25	49·2	39·3	9·1	2·4	+0·64	−0·08	Soil IIIB

The reaction of a water *per se* is of no consequence, since tests f, h and i show the effect at constant value of f = 0·1 of a neutral water compared with two that were slightly acid with HCl. Obviously only acid water that was buffered would exercise any effect. The bad effect of a purely saline water is shown by test g.

It is to be noted that the waters listed in Table 1 cover the types actually encountered in practice and described by Cassidy (1937, 1944) first for the Burdekin delta and since for the Queensland coastal region generally. A large number of analyses has indicated that very saline and very alkaline waters both have an f value as low as 0·5 and often much lower. It is this low value which causes degradation of the soil; for the low figure is the result of there being insufficient calcium and magnesium to offset the effect of the large amount of sodium chloride or the relatively large amount of sodium bicarbonate present in such waters.

A further conclusion to be drawn from Table 3 is that different soils react differently to the same water; those with high base exchange capacity resist change to a greater extent than do lighter soils. Such buffer action is the consequence of the greater number of ions which a soil of high exchange capacity can furnish to produce the reverse base exchange reaction. Thus it will be observed that waters 10 and 11 cause a smaller percentage saturation with sodium in the Burdekin soil (22 m.e. total bases) than in the Bellenden-Ker and Bundaberg soils, which have only seven milliequivalents and six milliequivalents respectively.

Field Results.

It now remains to examine the field evidence bearing upon these laboratory studies. The available data are collected in Table 4. From cases 11 and 12 representing adjacent farms the f value of the irrigation water is again seen to be the controlling factor in the entry of exchangeable sodium into the soil. In any case it is clear that a concentration of up to 54 grains per gallon of total solids had no very harmful effect on Ayr soils when the f value was greater than unity. The experience at Giru, a district near Ayr which lacks good irrigation water, shows a definite ingress of sodium ions due to an f value of 0·32 at 122 grains per gallon total solids (see soils 6 and 8). This conclusion was arrived at after allowing for soluble salt and calcium carbonate which were present in the soil. Even a two-inch irrigation at an f value of 0·2 has caused an increase in the small amount of exchangeable sodium originally present. The four soils from the Seaforth area of the Burdekin district provide an interesting series. Tapiolas's soil has apparently not increased in exchangeable sodium after many years of irrigated cultivation whereas Cabassi's soil shows considerable deterioration due to a low f value with 135 grains per gallon total solids. The high replaceable sodium in the Kalamia Estates soil is rather surprising if the most recent water analysis represents irrigation actually applied; but previous samples analysed have exhibited a lower f value.

Table

Effect of Irrigation Water

Soil No.	Soil.	Type of Irrigation Water.				Acre-inch Watering
		$\frac{Ca+Mg}{Na+K}$	Ca/Mg	Total Solids.	Free Alkali.	
				gr. p.g.	gr. p.g.	
1	J. Guy, Klondyke, Ayr	1·67	..	17	1	+
2	Ditto	0·84	..	24	7	20
3	D. Tooney, Klondyke, Ayr	1·67	..	17	1	..
4	Ditto	1·35	..	54	Nil	..
5	Cyprus Farming Co., Home Hill	0·6	1·2	60–200	Nil	+
6	J. L. Humphry, Giru	..	..	Nil	..	Nil
7	Ditto	0·2	..	80	4	2
8	Ditto	0·32	..	122	Nil	25
9	Christofides and Kallas, Seaforth, Ayr ..	..	..	Nil	..	..
10	Kalamia Estate, Seaforth, Ayr	0·1	..	95	Nil	..
11	Cabassi Bros., Seaforth, Ayr	0·14	..	135	9	..
12	B. Tapiolas, Seaforth, Ayr	1·08	0·8	45	Nil	..
13	Ditto (Drainage Water) ..	0·87	1·0	..	..	..
14	F. Clarke and Sons, Seaforth, Ayr	0·73	0·75	30	Nil	..
15	Ditto (Drainage Water) ..	1·0	0·67	..	..	..
16	W. Pearce, McDesme, Ayr	0·78	..	9	3	+
17	Ditto	0·18	..	38	29	30
18	G. Fordyce, Mackay	0·08	1·3	..	..	..
19	Ditto	..	..	Nil	..	Nil
20	Ditto	..	..	..	..	..
21	Ditto	..	..	..	..	..
22	Newlands Field Station, Nevada, U.S.A.* ..	1·03	33·6	15	..	..
23	Ditto*	..	..	..	..	..
24	Ditto (Drainage water)*	0·38	26·8	30–45	..	..
25	Ditto (Subsoil water)* ..	0·18	..	75–90	..	..
26	Mediterranean Loess Soil†	..	..	Nil	..	..
27	Ditto†	0·40	1·33	538	..	..
28	Californian Soil‡	0·20	1·8	60	..	..
29	Ditto‡	1·9	1·0	130	..	..

* Schofield, Moon, and Knight, 1936. † Puffeles, 1939. ‡ Eaton, 1935.

4.

upon Soil—Field Results.

Replaceable Bases in the Soil.								Remarks.
Ca	Mg	Na	K	Ca	Mg	Na	K	
m.e. per 100 g.				Per Cent of Total.				
15·6	4·0	0·57	0·57	75·3	19·3	2·7	2·7	+ A few years.
13·0	3·9	1·09	0·85	68·9	20·7	5·9	4·5	
18·2	6·5	1·00	0·47	69·6	24·8	3·8	1·8	
17·6	8·6	1·38	0·37	63·0	30·8	4·9	1·3	
..	..	..	..	60·8	30·0	7·4	1·8	+Several years.
19·8	..	0·28	..	..	..	..	..	No irrigation.
16·7	..	0·96	..	..	..	..	..	
+22·2	..	++5·41	..	..	..	..	..	+Includes 2 m.e. $CaCO_3$ ++2·6 m.e. Cl present.
14·6	6·5	0·88	0·71	64·4	28·6	3·9	3·1	No irrigation. Virgin soil.
12·3	8·2	3·08	0·28	51·7	34·2	12·9	1·2	
14·0	7·4	3·72	0·79	53·8	28·8	14·4	3·0	
..	..	..	..	64·1	29·8	4·3	1·8	
..	..	..	..	..	..	..	..	
..	..	..	..	..	..	..	..	
..	..	..	..	..	..	..	..	Adjusted for $CaSO_4$ taken from soil.
19·6	5·8	0·46	0·52	74·2	22·0	1·8	2·0	+A few years.
23·8	7·4	0·93	0·47	72·9	22·8	2·9	1·4	
..	..	..	..	..	..	..	..	Salt incrustation left by spring.
..	..	..	..	71·5	26·0	2·1	0·4	Normal soil ; not watered by spring.
..	..	..	..	50·2	31·5	17·5	0·8	Soil from affected area.
..	..	..	..	30·5	21·5	48·0	..	Soil from incrustation.
..	..	..	..	..	..	..	..	Either Ca and Mg have been given up by the water, or Na and K have been taken from the soil.
..	..	..	..	..	..	..	..	
..	..	..	..	..	..	..	..	
..	..	..	..	80·6	13·1	1·8	4·5	Original soil.
..	..	..	..	35·0	8·7	54·8	1·5	Permeability reduced to one-seventh of original.
..	..	..	..	..	..	..	..	In 9 years a pervious and highly productive soil was rendered impervious and unable to produce lucerne.
..	..	..	..	..	..	..	..	Lucerne and cereals still growing well after 18 years using this water.

The aggravating effect of high total salinity in addition to an unfavourable $\frac{Ca + Mg}{Na + K}$ ratio has been noted by Eaton (1935) and by Kelley, Brown and Liebig (1940). Data given by the latter authors appear to show that at their $^{Ca}/_{Na}$ ratio of 0·25 no entry of sodium occurs unless the total solids exceed 400 grains per gallon. However, these authors favour a ratio of unity as more desirable.

When the drainage water from a soil has a lower f value than the original irrigation water, a replacement from the soil of monovalent by divalent cations is indicated. Conversely, an increase in the f value of a water, whilst passing through a soil, indicates absorption of monovalent (sodium) ions by the soil with consequent deterioration of its structure. The previous indication that Tapliolas's soil has not been undergoing salt damage is borne out by the composition of the drainage water. This showed a tendency to an increase in monovalent and a decrease in divalent cations; meanwhile the unchanged chloride content proved that no concentration of the water had taken place. The small increase found in the sulphate content indicated that some soluble sulphate had been taken up from the soil. Of these data, only the f value and the $^{Ca}/_{Mg}$ ratio are shown in the table. The drainage water from F. Clarke & Sons had become concentrated to about twice the original value; when this was allowed for it was found that equivalent amounts of calcium and sulphate (obviously dissolved salts) had been taken from the soil. Making due allowance for this water-soluble calcium, the usual ratios were calculated and showed that the soil had possibly suffered some deterioration. The data of W. Pearce presents a definite anomaly. It is not known why the second water appears to have affected the soil to such a small extent. The Mackay soil has shown obvious effects from a salt spring which deposited an incrustation indicating an f value of 0·08. The drainage data of the Newlands Field Station are quoted by Schofield, Moon and Knight (1936) and when suitably recalculated show progressive concentration of the water to be accompanied by decreasing f values, *i.e.*, a water with an initial f of 1 has reacted favourably on the soil. Puffeles (1939) showed that a very saline water with an f value of 0·4 drastically reduced the permeability of a Mediterranean soil, the original soil having then become more than half saturated with sodium. Finally, Eaton (1935) has quoted the dual experience with a Californian soil, in one instance rendered sterile in nine years by irrigating at an f value of 0·2 but total solids only 60 grains per gallon, and in the other case producing good crops after 18 years with an f value of 1·9 but with total solids 130 grains per gallon.

The laboratory experiments have therefore been corroborated by field results derived from many parts of the world, and it appears that entry of sodium ions into the exchange complex of a soil may definitely be expected if the f value of the water applied does not exceed 0·5.

Permanence of Degree of Sodium Saturation.

Before proceeding to consider the properties of soils saturated to various degrees with sodium ions, it is important to know something of the persistence of the condition under the action of different leaching solutions. Furthermore, Queensland irrigated soils are liable to be subjected from time to time to leaching by heavy rains. Sometimes also there may be a change in the quality of irrigation water applied. The practical questions are obvious. Is it safe to rely on the alternation of rainfall with saline irrigation to counteract the serious effect of the latter on the soil? How can a salt-affected soil be reclaimed? Table 5 sets out some of the data found. It is clear that distilled water (for this purpose the equivalent of rain) has effectively reduced replaceable sodium in all cases. The reclaiming effect of irrigation water No. 12 having an f value of unity is also obvious, regardless of the fact that this water has a total salinity of more than 100 grains per gallon. It is satisfactory to note that each soil type

Table 5.

ILLUSTRATING THE DYNAMIC NATURE OF THE RELATION BETWEEN SOIL AND WATER.

Soil Type.	Sample Used.	Amount of Leaching (acre-ins.).	Replaceable Bases. (Per Cent. of Total.)			
			Ca	Mg	Na	K
Effect of Distilled Water.						
Burdekin Alluvial ..	Cultivated soil ..	Nil	64·1	29·8	4·3	1·8
		43	62·2	33·0	2·9	1·9
Bellenden-Ker Alluvial..	Soil II.	Nil	69·5	16·2	5·3	9·0
		25	69·6	17·3	2·7	10·4
	Soil IIA.	Nil	34·4	41·8	18·4	5·4
		25	44·2	43·6	5·7	6·5
Bundaberg Red Forest..	Soil III.	Nil	70·7	21·9	2·2	5·2
		25	55·5	40·8	1·0	2·7
	Soil IIIA.	Nil	39·0	44·8	14·9	1·2
		25	39·2	52·6	6·8	1·4
Effect of Irrigation Water No. 12 (f = 1·02).						
Burdekin Alluvial ..	Soil IA.	Nil	54·2	35·2	9·2	1·4
		25	59·7	33·3	5·7	1·3
	Soil IB	Nil	60·6	31·7	5·4	2·2
		25	62·3	29·6	6·4	1·7
Bellenden-Ker Alluvial..	Soil IIA.	Nil	34·4	41·8	18·4	5·4
		25	54·5	29·2	10·9	5·4
	Soil IIB.	Nil	52·0	29·2	12·4	6·4
		25	57·3	28·9	9·9	3·9
Bundaberg Red Forest	Soil IIIA.	Nil	39·0	44·8	14·9	1·2
		25	64·2	27·8	6·3	1·7
	Soil IIIB.	Nil	49·2	39·3	9·1	2·4
		25	62·6	28·4	6·3	2·7
Effect of Irrigation Water No. 10 (f = 0·27).						
Burdekin Alluvial ..	Soil B_2	Nil	59·3	23·8	15·8	1·1
		25	60·0	17·3	21·4	1·3

gave substantially its own characteristic percentage distribution of exchangeable bases after the final leaching with water No. 12, although the distribution was quite different in both the original soil and in the two intermediate subsamples. All this shows that the reaction of soil and water is, at least in a chemical sense, reversible, and the last water applied (if in sufficient quantity) determines the final state of the soil. In the case of distilled water it is necessary to add that the dispersed condition of a soil partially saturated with sodium ions may reduce the leaching to a negligible rate. In fact Soil A percolated only 10 acre-inches in 10 days under the conditions of the experiment and Soil F proved perfectly impervious to distilled water after having allowed only one acre-inch to pass (see Table 8 for comparable values of other soils). In some extreme cases therefore reclamation by natural leaching under rainfall only becomes an impossibility.

Effect of Replaceable Sodium on Physical Properties of Soil.

Having examined the conditions for the entry of sodium into the soil it remains to find the influence which various amounts of replaceable sodium exert upon the soil. Four different means of detecting physical changes in the soil were tried. The measurements made were the moisture equivalent, the Keen-Raczkowski constants (Keen and Raczkowski, 1921), the rate of percolation of water and the hardness of the soil surface after drying.

Moisture Equivalent.—It was soon found that the moisture equivalent has no value in discriminating between differently treated samples of the same soils. In the first case, because nearly all soils are in good physical condition at the moisture equivalent, no significant differences in the measurements are obtained, and in the second case, soils with a high degree of sodium saturation become so impervious when dispersed that on spinning in the centrifuge excess water is separated at the surface of the soil-cake instead of draining off through the soil.

Keen-Raczkowski Constants.—Coutts' (1930) modified cylindrical box was used, but the soil was put through a 2 mm. sieve instead of through the 100 mesh specified. This avoided unnecessary change of the soil structure. Results of definite significance were obtained. A preliminary testing of the accuracy of the method was made on the virgin Burdekin soil with the test for significance given by Livermore and Neely (1933). Soil fresh from the field was used in six replicates and a further three replications were made on an air-dried sample which had been re-moistened, sieved and dried, with a minimum of working. The results are given in Table 6. The equivalence of the two sets of measurements is satisfactory, for it is most convenient to store soil samples in the air-dry condition.

The whole series has been used to calculate the significant difference between means of any two treatments when duplicate determinations are made and odds are 30:1. It should be noted that the differences given are not for fresh soil and air-dried soil, but for any two treatments regardless of whether or not *careful* remoistening and air-drying have been carried out. Having

Table 6.

ILLUSTRATING THE PRECISION OBTAINABLE IN THE KEEN-RACZKOWSKI TEST.

	Moisture.	Apparent Sp. Gr.	Water Capacity.	Pore Space.	True Sp. Gr.	Volume Expansion.
	Per Cent.		Per Cent. by Wt.	Per Cent. by Volume.		Per Cent.
Fresh Soil	10·05	1·04	62·3	56·9	2·25	Trace
		1·03	63·1	56·8	2·23	Nil
		1·02	62·9	56·6	2·21	Nil
		1·00	61·7	54·3	2·04	Nil
		1·09	63·6	55·3	2·25	4·0
		1·09	62·5	55·0	2·27	2·3
Air Dried Soil	5·12	1·00	60·3	55·9	2·12	2·4
		1·03	58·4	55·8	2·17	2·6
		0·97	63·0	57·6	2·18	1·1
Significant Difference of Constants		±0·09	±3·5	±2·1	±0·11	±3·1

established the precision of the method for the conditions under which it was to be used, it was then possible to examine the treated samples containing various amounts of exchangeable sodium. At the same time it was deemed advisable to study the ill-effect of mechanical handling alone on the soil. To this end the air-dried sample of original virgin soil was subjected to grinding of various intensities in a porcelain mortar. In all cases a "pencil grip" of the pestle and not a "fist grip" was employed. The lightest grinding involved only just enough treatment with the pestle to break lumps so as to pass the 2 mm. sieve. As some of the tests were made with more than two replications the differences necessary for significance are in those cases somewhat less than the maximum values already quoted. It is clear from Table 7 that any large increase in replaceable sodium reduces both water-holding capacity and pore space of the virgin soil by as much as 20 per cent. of the original values. The reduction does not appear to commence until sodium constitutes about 15 per cent. of the total replaceable bases. This does not support the opinion of Ratner (1935), who asserts that much damage has resulted by this stage. The damaging effect of dry-working the soil is illustrated in the second portion of the table. It is possible that this factor is the more important one in the deterioration of Burdekin soils, as a search covering several years has shown only one or two examples of a soil with sodium constituting as much as 20 per cent. of the total replaceable bases. Moreover, the usually very desiccating climatic conditions prevailing for much of the year leaves the soil in an unsuitably dry state for ploughing, and farmers are doubtless loth to irrigate their land for this purpose only. Further, tests by the author have shown that the dry working of Burdekin soil already partially saturated with sodium, greatly increases the hardness of the soil crust which is formed when the soil dries. Table 7 shows also the increase in apparent density which has resulted from grinding the soil, little change being shown in the true specific gravity as determined by the Keen-Raczkowski method.

Table 7.

PHYSICAL CHARACTERISTICS AS AFFECTED BY INCREASED EXCHANGEABLE SODIUM AND BY MISHANDLING THE SOIL.

Soil and Treatment.	Apparent Specific Gravity.	Water Capacity.	Pore Space.	True Specific Gravity.	Volume Expansion.	No. of Replications.	Per Cent. Replac. Sodium.
		Per cent.	Per cent.		Per cent.		
Virgin Soil ..	1·03	62·0	56·1	2·21	1·4	9	4·1
Soil E	1·01	64·1	59·0	2·34	3·3	2	8·3
Soil C	1·04	59·7	56·7	2·28	4·4	2	12·0
Soil D	1·11	54·9	53·4	2·26	6·0	2	16·5
Soil F	1·10	50·1	48·5	2·08	Negative	2	84·9
Soil A	1·08	52·1	53·0	2·22	Negative	2	16·8
Soil B_2	1·04	58·7	55·9	2·24	4·6	2	21·4
Sig. Difference ..	±0·07	±2·7	±1·6	±0·09	±2·4	..	..
Fresh Soil ..	1·04	62·7	55·8	2·21	1·1	6	4·1
Dry Soil Remoistened—							
Minimum handling ..	1·00 ± 0·06	60·6 ± 2·4	56·4 ± 1·5	2·16 ± 0·08	2·0 ± 2·2	3	4·1
Light grinding	1·10 ± 0·07	54·3 ± 2·8	56·2 ± 1·6	2·20 ± 0·09	2·1 ± 2·5	2	4·1
Severe grinding	1·16 ± 0·06	50·7 ± 2·4	50·8 ± 1·5	2·13 ± 0·08	8·7 ± 2·2	3	4·1
Severe grinding	1·18 ± 0·06	48·4 ± 2·2	51·3 ± 1·4	2·24 ± 0·07	5·8 ± 2·0	4	4·1

Percolation Rates.—As a practical test of the soil's actual reaction to the treatment it had received, a very simple percolation test was devised. Cylindrical glass funnels 25 cm. long and 4·5 cm. in diameter, and provided with a glass tap, were fitted with equal-sized filtering pads of cotton wool. Distilled water was added to a mark at 20 cm. above the tap, the air bubbles were removed, and the pads were adjusted to give equal rates of delivery when the cylinders contained no soil. Fifty grams of dry soil were then added to each cylinder and the rate of flow measured, the total head being kept constant to within 2 cm. The filter pads offered a resistance to flow which was negligible compared with that of the soil. A constant-level device would probably have been an improvement, but with sufficient care it was possible to obtain closely reproducible values. The results of these tests are recorded in Table 8 and also shown graphically in Figure 1.

The lower portion of Figure 1 refers to the Burdekin soil and to forms of it containing various amounts of replaceable sodium. The details are to be found in Table 8. The cross-checked curve refers to soil *c*, after it had suffered severe dry working.

The upper portion of Figure 1 refers to the Bellenden Ker and Bundaberg soils, before and after the ingress of exchangeable sodium. The influence of exchangeable sodium in depressing the permeability of the soils is clearly shown by these curves.

Table 8.

PERCOLATION RATES OF SOILS.

Soil Type.*	Sample Used.	Total Volume of Percolate (ml.).†						Average Rate for 30–60 min. Period. (ml. per min.)		Per Cent. Sodium in Replaceable Bases.
		5 Mins.	10 Mins.	15 Mins.	20 Mins.	30 Mins.	60 Mins.			
Burdekin Alluvial	Virgin soil, air dried	60	115	177	..	250	400	5·0		
		..	110	142	..	222	336	3·8	4·4	4·1
		75	116	155	181	234	362	4·3		
	Virgin soil, air dried, remoistened, and sieved	40	50	55	..	69	..	0·5	0·8	4·1
		49	50	..	..	104	138	1·1		
	Soil E	47	70	95	..	154	268	3·8	3·6	8·3
		62	95	124	..	190	288	3·3		
	Soil C	82	135	180	218	293	464	5·6		
		84	136	181	222	294	465	5·7	5·8	12·0
		60	132	..	215	313	520	6·9		
		73	125	162	..	260	489	5·0		
	Soil C—Lightly ground	45	75	98	..	159	..		3·2	12·0
	Soil C—Severely ground	46	65	83	96	119	168		1·6	12·0
	Soil D	20	23	..	29	33	40	0·2	0·2	16·5
		20	24	25	..	35	40	0·2		
	Soil A	25	40	43	..	51	65		0·5	16·8
	Soil B_2	10	10	10	10	10	10		0·0	21·4
	Soil F	10	10	10	10	10	10		0·0	84·9
Bellenden-Ker Alluvial	Soil II—Cultivated	64	105	135	..	209	345		4·5	5·3
	Soil II_A	58	90	113	..	164	250		2·9	18·4
Bundaberg Red Forest	Soil III—Cultivated	130	190	227	..	314	450		4·5	2·2
	Soil III_A	97	148	183	..	259	380		4·0	14·9

* For the composition of these soils, *see* Table 3.

† 33 ml.≡1 acre-inch.

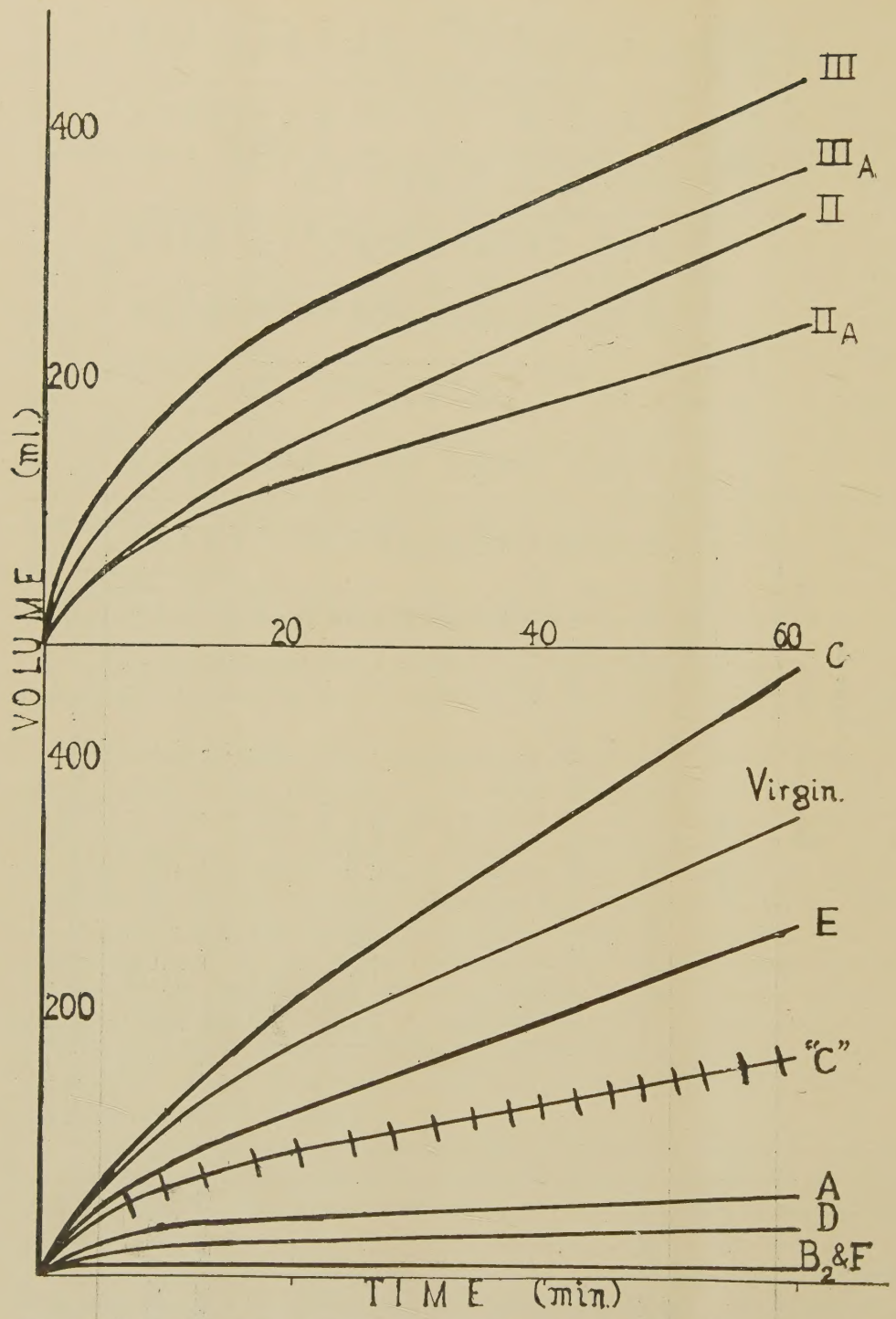

FIG. 1.—Showing the Effect of Exchangeable Sodium on the Percolation Rates of Soils. (See Table 8.)

No claim is made to any high degree of precision for this method, as in one instance a distinct anomaly is obvious (curve 1 lying above curve 4); nevertheless it is clear that as replaceable sodium increases the soil becomes less permeable. There appears to exist a critical value for this sodium content in the vicinity of 15 per cent., since soils with values greater than this are virtually impervious.

Hardness of Soil Crusts.—The most obvious characteristic of any "puddled" soil is the hardness of both the crust formed on the surface and the large clods turned up by ploughing. As a comparative measure of this property readings were made with an instrument designed to indicate rind hardness of sugar-cane, and described by Buzacott (1940). The penetration tests were made on soil treated as follows:—Fifteen grams of soil were placed in a 4 cm. moisture equivalent dish, the soil being allowed to become saturated by standing the dish in water (to the level of the soil); it was then drained and air-dried to remove most of the water, and finally dried at 105° C. Readings were taken as the needle of the penetrometer penetrated the soil cakes. Table 9 shows that the Burdekin alluvial soils showed an increase in hardness as more sodium entered the soil; this effect was not shown by the other two soils. A small effect due to dry working was also shown by all soil types.

Table 9.

SHOWING THE RESULTS OF PENETROMETER TESTS.

Soil.	Hardness (Divisions).
Burdekin alluvial—	
Virgin soil	1
Virgin soil (dry ground)	4
Soil E (8·3% Na)	7
Soil D (16·5% Na)	17
Soil A (16·8% Na)	20
Soil B_2 (21·4% Na)	Beyond range of Instrument.
Soil F (84·9% Na)	
Bellenden-Ker alluvial—	
Normal soil	2
Normal soil (dry ground)	4
Soil IIA (18·4 % Na)	1
Bundaberg red forest soil—	
Normal soil	1
Normal soil (dry ground)	4
Soil IIIA (14·9 % Na)	1

Further tests have been made on these soil types and on one other soil in an attempt to elucidate the effects in general of physical mismanagement of soils. It is hoped to report in a subsequent paper the results of this work.

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